Chapter 6

SITE PLANNING AND DESIGN CONSIDERATIONS

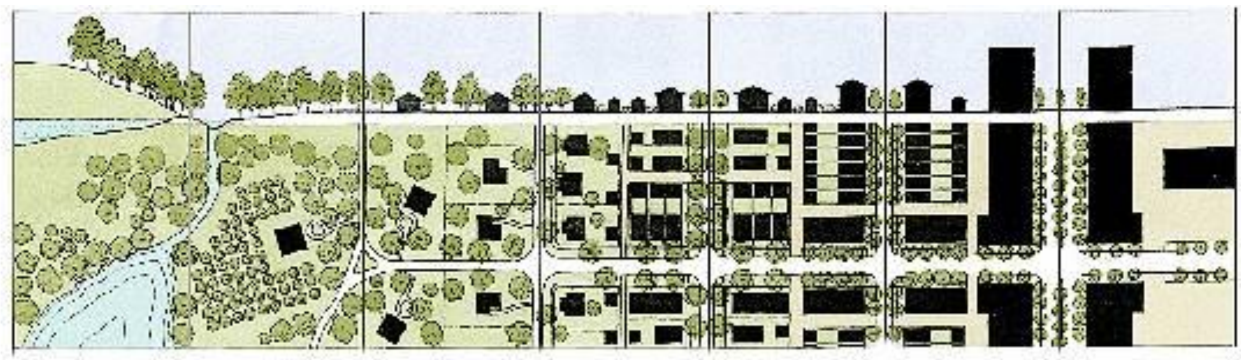
Table of Contents

CHAPTER SECTION HEADINGS

FIGURES

TABLES

APPENDICES



6.0. INTRODUCTION

As research, technology, and information transfer have improved over recent years, alternative approaches are being sought by citizens and governments to reduce the impacts of stormwater runoff from new development and redevelopment. Developers and designers also are seeking alternatives to expedite permitting processes, reduce construction costs, reduce long-term operation and maintenance costs, and increase property values.

Careful site planning at the outset of a project is the most effective approach for preventing or reducing the potential adverse impacts from development. Site planning is a preventive measure that addresses the root causes of stormwater problems. In the past, "stormwater management" has been defined largely as stormwater *disposal*. Stormwater management in Virginia can be significantly improved by approaching the task differently than this. A new and better approach is based on a conceptual understanding of stormwater, which is more comprehensive in scope and addresses the full array of stormwater issues.

In order to protect Virginia's water resources, we must pay attention to recharging groundwater and maintaining a balance in the hydrologic cycle, preventing flooding, and maintaining water quality and the ecological values that have historically characterized Virginia waters. This different perspective further challenges us to prevent stormwater from becoming a problem, and to avoid highly engineered structural solutions that are expensive to both build and maintain. Where feasible, this new approach focuses on using natural systems and processes to achieve stormwater management objectives.

At the same time, this new approach is intended to enhance the natural functions of beneficial site resources. The end result is a site design that enhances existing wetlands, promotes the critical functions of floodplains, and integrates with riparian buffer systems, even while satisfying stormwater requirements. This approach maximizes the value achieved for the money spent.

The purpose of this chapter is to provide guidance for managing stormwater at land development projects in a manner that provides the optimum opportunity to protect and conserve natural resources, maintain the pre-development hydrologic regime, minimize the potential negative impacts of stormwater runoff, and minimize the human "footprint" on the environment.

While reducing the impacts from stormwater runoff may be achieved through both regulatory and non-regulatory techniques, this chapter focuses on the site-level planning and design tools that provide the best opportunity to accomplish the above goals. The techniques for doing this most effectively are represented under the banner of the terms “Better Site Design,” “Sustainable Site Design,” or, as DEQ prefers to label it, “Environmental Site Design”(ESD).

6.1. ENVIRONMENTAL SITE DESIGN

How do we describe Environmental Site Design, and how does it differ from “Conventional Design?” Environmental Site Design incorporates non-structural and natural approaches to new development and redevelopment projects to reduce impacts on watersheds by conserving natural areas, reducing impervious cover and better integrating stormwater treatment into the landscape. The aim of environmental site design is to reduce the environmental impact, or “footprint,” of the site while retaining and enhancing the owner/developer’s purpose and vision for the site. Many of the environmental site design concepts employ non-structural on-site treatment that can reduce the cost of infrastructure while maintaining or even increasing the value of the property relative to conventional designed developments.

For the purposes of this chapter, Conventional Design can be viewed as the style of suburban development that has evolved over the past 50 years, which generally involves larger lot development, clearing and grading of significant portions of a site, wider streets and larger cul-de-sacs, large monolithic parking lots, enclosed drainage systems for stormwater conveyance, and large “hole-in-the-ground” detention basins.

It is important to point out that Environmental Site Design (ESD) techniques/practices are *not* the same thing as Low Impact Development (LID) practices, and vice versa, although these strategies overlap and complement one another. The goals of environmental site design are set out in the following section. The goal of LID is to manage the process by which each site responds to hydrologic and hydraulic impacts of development through the use of a specific array of practices.

Environmental site design employs small-scale stormwater management practices, non-structural techniques, and better site planning to mimic natural hydrologic runoff characteristics and minimize the impact of land development on water resources. This includes:

- Optimizing conservation of natural features (e.g., drainage patterns, soil, vegetation, etc.);
- Minimizing impervious surfaces (e.g., pavement, concrete channels, rooftops, etc.);
- Slowing down runoff to maintain discharge timing and to increase infiltration and evapotranspiration on the development site; and
- Using other non-structural practices or innovative technologies approved by DEQ.

Each ESD practice incrementally reduces the volume of stormwater on its way to the stream, thereby reducing the amount of conventional stormwater infrastructure required. ESD principles and practices are considered at the earliest stages of design, implemented during construction, and sustained in the future as a low-maintenance natural system. Also, it is important to recognize that ESD practices are more appropriately applied to greenfield development, where there is ample space and soil conditions to apply the principles and practices. ESC principles may be difficult to apply at typical redevelopment sites, where space is limited and costly and "urban" (mixed, dense) soils exist.

Environmental site design is intrinsically associated with the concept of sustainability and the emerging *sustainable site design* movement, reflected in the 2009 release of the Sustainable Sites Initiative™ (SSI), an interdisciplinary partnership of the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center at the University of Texas at Austin, and the National Botanic Garden (see ASLA et al., 2009a and 2009b). For more information on the SSI, including a discussion of its scoring and certification criteria, see **Appendix 6-E** of this chapter.

6.1.1. Environmental Site Design Principles

Environmental Site Design techniques are mostly applied at sites of new development. It is more difficult to achieve ESD at redevelopment sites due to lack of space, compacted soils, and the constructed drainage system and utilities that are already in place. There are several very important principles involved in accomplishing ESD effectively.

6.1.1.1. Achieve Multiple Objectives

Stormwater management should be comprehensive in scope, with management techniques designed to achieve multiple stormwater objectives. These objectives include managing both the peak flow rate and total volume (i.e., balance with the hydrologic cycle of the site), as well as water quality control and water temperature maintenance. Comprehensive stormwater management involves addressing all of these aspects of stormwater.

"Treatment train" configurations with multiple structural techniques may be required in some situations in order to achieve comprehensive objectives. However, the objective in ESD is to try to achieve multiple comprehensive objectives with simpler, rather than more complex, management systems.

6.1.1.2. Integrate Stormwater Management and Design *Early* in the Site Planning and Design Process

In the past, the street and lot layouts of development sites have been decided upon first, often based on criteria that have little or nothing to do with the site's natural features or ecology. Stormwater control measures would then be squeezed into leftover spaces on the site, whether or not they were best suited for this purpose. Tacking stormwater management decisions on at the *end* of the site design process almost invariably leads to less than ideal results.

For comprehensive stormwater management objectives to be optimized, stormwater management must be incorporated into site design from the outset, integrated into the concept/sketch plan phase of development, just as traffic and circulation are integrated at that stage. In fact, the configuration of the natural drainage system and management of runoff generated by the development should carry significant weight in determining the site's use and the site plan configuration. Along with early site mapping and natural resource inventory (see **Figure 6.1** below), site planners need to consider incorporation of ESD techniques and practices into the overall site design process, and not engineer them after the fact.

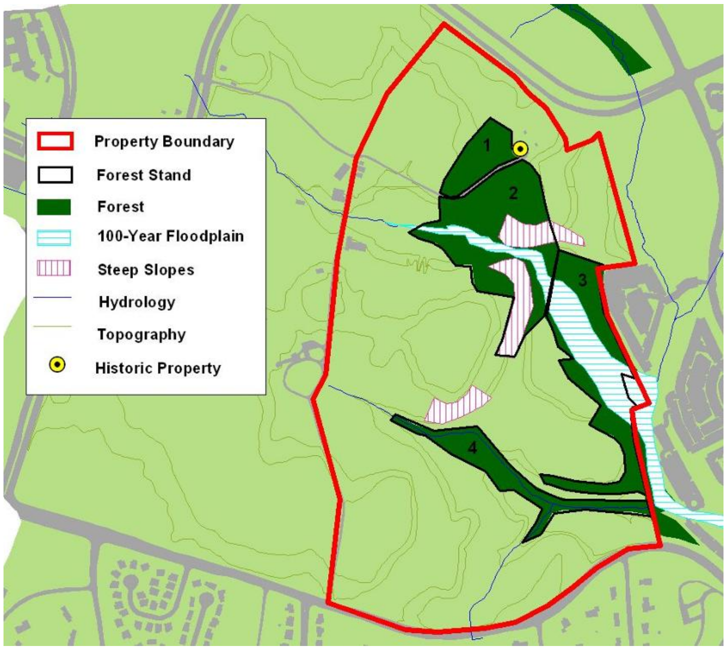


Figure 6.1. Site Natural Resource Inventory Map
Source: Chesapeake Bay Stormwater Training Partnership

6.1.1.3. Prevent Problems to Avoid Having to Mitigate Them

The first objective in stormwater management strategizing is *prevention*. Approaches to site design which can reduce stormwater runoff generation from the outset are the most effective, although such area-wide *planning* decisions are typically not actually thought of as stormwater management per se. For example, effective clustering significantly reduces the length of roads and, thus, the amount of imperviousness, when compared to conventional development. Arrangement of units with minimal setbacks reduces driveway length, thus, the amount of imperviousness. Reduction in street width and other street design considerations further subtract from total impervious cover. Such important elements of site design are rarely thought of as part of conventional stormwater management practices, yet they result in significant stormwater quantity and quality benefits.

6.1.1.4. Conserve Resources and Minimize Land Cover Changes

Minimization of impacts refers to reducing the extent of construction and development practices that adversely impact the hydrologic conditions of the site. This includes limiting the clearing and grading of land to the minimum needed to construct the development and associated infrastructure. Conserving specific sensitive lands on a site is a crucial early step in the planning process. Obviously, any areas of a site that are conserved will not be converted to impervious cover. The general benefits of conservation can be enhanced by locating and protecting certain hydrologic features such as drainage paths, permeable soils, steep slopes, etc.; and, in accordance with appropriate zoning and subdivision requirements, strategically locating setbacks, easements, woodland conservation zones, buffers, utility corridors, and other permanent site features to enhance the overall goals of maintaining the pre-developed hydrology (LIDWG, 2005).

Fixed improvements such as roads, houses or buildings, sanitary and storm sewer utility corridors, etc., should be located on the site so as to minimize unnecessary grading and/or compaction of the natural soil horizon, clearing of trees, and creating of impervious surfaces (LIDWG, 2005). Specific recommendations include:

- Reducing the size of cleared area (i.e., preserve as much woodland as possible) and reforest areas of the site where feasible.
- Locating cleared/graded areas outside of permeable soils and vegetated areas.
- Minimize the use of turfgrass (which requires more maintenance, fertilizer and pesticides) by establishing more naturalized landscaping with native vegetation
- Designing roads, sidewalks, and parking areas to minimize land cover impacts.

6.1.1.5. Design the Development to Fit the Terrain

Developments that are designed to "fit the terrain" of the site require significantly less grading and soil disturbance than those that are designed without regard for the existing topography. Road patterns should match the landform by placing roadways parallel to contour lines where possible. In doing so, natural drainageways can be constructed along street rights-of-way, thereby reducing the need for storm pipe systems. Open space development, allowable in many municipalities, can help preserve large natural areas and open space as well as make it possible to design around topographical constraints.

6.1.1.6. Apply Decisions that Have the Effect of Maintaining the Natural Site Hydrology

The most common parameter used to account for changes in site condition is the runoff curve number (CN). As the value of the site's CN increases from the pre-development condition to the post-development condition, temporary storage becomes necessary to mimic the pre-development CN. Site development factors most responsible for the determination of the CN are generally related to the land cover type. Of specific concern is the area of impervious cover as a fraction of the total site area, since it has such a pronounced effect on the hydrologic response of the site. Other factors include the soil infiltration rate and condition of the land cover. Key objectives in mimicking the site's pre-development hydrology include preserving the site's runoff rate and patterns, maintaining the pre-development volume, frequency, and duration of runoff, and sustaining groundwater recharge, stream baseflow and stream water quality. Ideally, the post-development drainage patterns and time of concentration (Tc) should closely resemble those of the pre-development condition. The Tc, in conjunction with the CN, determines the peak discharge rate for a storm event. From theoretical considerations, site and infrastructure components that affect time of concentration and travel time include:

- Travel distance (flow path);
- Slope of the ground surface and/or water surface;
- Ground surface roughness; and
- Channel shape and pattern.

These concepts are applied to ESD by using techniques that control the Tc by modifying the following aspects of flow and conveyance within the development:

- Maximize sheet flow;
- Modify/lengthen the flow path;
- Minimize site and lot slopes;
- Disconnect impervious area runoff
- Use open swale drainage; and
- Maximize site and lot vegetation.

6.1.1.7. Manage Stormwater As Close to the Point of Origin (Generation) As Possible; Minimize Collection and Conveyance

From both an environmental and economic perspective, redirecting runoff back into the ground, as close to the point of origin as possible costs less money and maintains natural hydrology. Pipes, culverts, and elaborate systems of inlets to collect and convey stormwater work against management objectives, in most cases increasing the challenges of managing stormwater holistically. Such systems increase flows and increase rates of flow, all making erosive stormwater forces worse. Structural collection and conveyance systems are increasingly expensive, both to construct and maintain. Furthermore, almost without exception, these systems suffer from failures and, therefore, should be avoided if at all possible. A corollary principle is to avoid concentrating stormwater flows, which is achieved when stormwater is not conveyed long distances, but rather recycled into the ground at or near the source.

6.1.1.8. Rely to the maximum on natural processes that occur within the soil and the plant community

The soil offers critical pollutant removal functions through physical processing (filtration), biological processing (various types of microbial action), and chemical processing (cation exchange capacity and other reactions). Plants similarly provide substantial pollutant uptake/removal potential, through physical filtering, biological uptake of nutrients, and even various types of chemical interactions. The final destination of pollutants is important. Pollution is often just a resource out of place – too much of a good thing in the wrong location; elements that are often useful to vegetation and within the soil mantle. Natural processes can work effectively to minimize these types of pollution problems.

Environmental site design is based on a philosophy – a vision for the environment – that is neither pro-development nor anti-development. Environmental site design is grounded on the positive notion that environmental balance can be maintained as new communities are developed throughout our watersheds, if basic principles are obeyed. Environmental site design means understanding our natural systems such as our essential water resources and making the commitment to work within the limits of these systems whenever and wherever possible. As stated above, ESD is grounded on recognition of a principle stated in **Chapter 4**: that stormwater is ultimately a precious resource to be used carefully, rather than a waste product in need of disposal.

6.1.2. Soils and Vegetation Provide Key Natural Processes in Environmental Site Design

Before describing specific aspects of ESD, a quick review is in order regarding the nature and extent of the natural systems and processes that are important to the success of the ESD solutions. Keep in mind that the following information is very much condensed; numerous details have been omitted for the sake of brevity and user friendliness.

6.1.2.1. Soil-Linked Processes for Water Quality/Quantity Management

Soil constitutes an extremely valuable resource, and documenting the complete array of these soil-based processes would require a separate Handbook altogether. Environmental site design, as with other stormwater control measures, relates in important ways to the soil mantle and the manner in which water moves across and through this soil. Understanding how much of what type of soil is in place is essential when assessing stormwater impacts and stormwater management needs. The type of soil existing on a site may turn a management problem into an opportunity. For example, soil type influences how much water can be infiltrated per time period, based on soil permeability. Soil permeability rating, therefore, is a critical variable in ESD. Soil type will also affect pollutant removal potential. Soil erodibility is an important factor as well. Factors such as depth to bedrock and depth to seasonal high water table also have important ramifications for ESD.

Soil surveys, provided by the USDA-NRCS on a county-by-county basis, provide a considerable amount of information relating to all relevant aspects of soils. Soil with a coarse texture (i.e., having large particle size such as sand) has a high rate of infiltration. Soil with extremely small particle size (clayey soil) has a low rate of infiltration. Understanding these soil characteristics is an essential first step in ESD. When dealing with structural practices which rely on infiltration (e.g., infiltration basins and trenches, dry wells, etc.), the Hydrologic Soil Group (HSG) classification and permeability rating is crucial for determining success. Typically a permeability of at least 1/2-inch per hour is required for structural control measures. Because ESD often does not involve the type of soil disturbance and potential compaction problems that can occur with construction of structural controls, somewhat lower permeability – perhaps as low as 1/4-inch per hour – can be tolerated and put to good use. However, when permeability rates are that low, extreme care must be taken with design and construction, because there is little margin for error. Furthermore, it is possible that locating an infiltration BMP on soils with such a low permeability may result in a larger footprint for the practice. So the trade-offs must be considered carefully.

At the same time areas of such poor permeability but with good stands of vegetation may function quite satisfactorily and offer opportunity which should not be ignored at a site (a well-developed root zone associated with established vegetation can significantly improve poor soil infiltration and permeability). For example, an otherwise questionable HSG C soil, if not disturbed and if reasonably well vegetated, may offer surprisingly good opportunity for receiving and infiltrating stormwater created by new impervious surfaces elsewhere on the site. The presence of stems and roots can substantially enhance infiltration and permeability. Conversely, even seemingly good soils (HSG B), if substantially disturbed and compacted, can become far less permeable, as is typical of the yards in many mass-graded residential subdivisions. In such cases permeability ratings should be reduced. However, sandy HSG A soils may be able to withstand disturbance problems more readily than heavier soils with clay content, and therefore may not experience this same kind of loss of permeability.

Although reliance on the published soil data is acceptable for most feasibility studies and conceptual planning, detailed planning should be accompanied by field sampling (using saturated bore holes) and verification of soil types and classes. The size of the site, geologic complexity, and other factors will determine the number of bore holes necessary at each site.

Soils are very important for their ability to remove pollutants entrained in stormwater, through a complex of physical, chemical, and biological mechanisms. Above all, the soil mantle must be understood to be a vast and complex system, a rich and diverse community of organisms – thousands, even millions of organisms per cubic inch – all of which have complex functions which can become the basis of impacts if damaged or destroyed, or become mechanisms for treatment if understood and properly used. The various types of processes which occur as the result of soil microbe action and the other essential elements of the soil community, when fully understood, can be used quite effectively for stormwater management purposes. Soil microflora are abundant and diverse, including innumerable species of bacteria, fungi, actinomycetes, algae, and viruses. These species process organic material (one type of stormwater-linked pollutant) as food and energy sources in various ways. Physically, particulate pollutants are caught and filtered by the soil mantle as well. Many of the soil-based functions which are chemically-oriented (e.g., adsorption, etc.) occur through the mechanisms of cation exchange driven by, among other factors, surface area of soil particles. Such functions are especially important for their ability to remove soluble pollutants such as nutrients. Even in large particle sandy soils where surface area is low (72 sq cm per gram), significant pollutant reduction can occur through these chemical mechanisms. Cation exchange capacity (CEC) is used as a measure of pollutant reduction potential and can be determine through soil testing.

Pollutant removal potential often varies indirectly with permeability. For example, soils that are extremely sandy (large particle size, fewer particles) can be expected to have excellent permeability but borderline CEC values. In fact extremely sandy soils may have such low CEC values that they are typically not as effective in removing either soluble or particulate pollutants from stormwater. In no way should “hot spot” runoff from roads, gasoline stations, auto repair centers or fast food parking lots be cycled through sandy infiltration systems without being pretreated through some sort of filtering mechanism. Conversely, heavy clayey soils may have limited permeability, yet typically do an excellent job of removing a wide variety of pollutants due to their high CEC ratings.

6.1.2.2. Vegetation-Based Processes for Water Quality and Quantity Management

Vegetation provides a host of useful functions which are vital to effective environmental site design. These functions typically reflect the close connection between water quantity and water quality issues:

- Vegetation absorbs the energy of falling rain, promoting infiltration, minimizing erosion, etc.
- Roots hold soil particles in place, like structural steel in reinforced concrete, preventing erosion.

- Vegetation (blades, stems, trunks, etc.) provides friction that slows runoff velocity and filters out particulate pollutants; as the velocity slows, not only is the erosive force reduced, but sediment already entrapped will begin to settle out, as will other pollutants. Reduced velocity also means increased opportunity for infiltration.
- Vegetation provides for a richer organic soil layer which improves soil porosity and structure, maximizing the absorptive capacity of the soil and promoting infiltration.
- Vegetation "consumes" many different types of stormwater-linked pollutants through absorption from the root zone. In addition to the positive effects on sediment and sediment-bound phosphorus, even solubilized nitrogen is taken up through a series of complex processes and transformations, as are some metals and other compounds.

6.2. STORMWATER MANAGEMENT THROUGH ENVIRONMENTAL SITE DESIGN

In the context of stormwater management, the goal of environmental site design should be to promote runoff control through the use of the natural drainage system and to reduce the environmental impacts of commonly used land development and drainage methods. In addition to maintaining natural drainage, ESD should (1) provide a natural open-space based drainage system using undeveloped flood plains and drainage swales; (2) avoid channelization within the natural drainage system; and (3) maintain forest cover and other natural vegetation to the extent feasible. These practices will result in maintenance or enhancement of the normal water table level.

By maintaining or restoring the natural drainage system, runoff from even a 100-year storm should be managed with minimal problems. Runoff generated by higher frequency storms (e.g., 5-10 year storms) should be handled on the individual sites. At the site scale, runoff can be managed in various ways, including (1) capturing it for reuse on the site; (2) directing it to primary and secondary swales where vegetation will retard flow and allow water to infiltrate permeable soils; (3) holding it on identified recharge areas; and (4) directing it into detention and retention facilities, as necessary.

Development projects can be designed to reduce their impact on watersheds when careful efforts are made to conserve natural areas, reduce impervious cover and better integrate stormwater treatment. By implementing a combination of these nonstructural ESD approaches, it is possible to reduce the amount of runoff and pollutants that are generated from a site and provide for some nonstructural on-site treatment and control of runoff. The volume of stormwater runoff and the mass of pollutant loads can be reduced as much as 20-60 percent on most development sites (even up to 100 percent on some sites) simply by implementing the land development principles and practices advocated in this chapter. When applied early in the site design and layout process, environmental site design techniques can sharply reduce stormwater runoff and pollutants generated at a development site, and also reduce the size and cost of both the stormwater conveyance system and stormwater management practices. Important stormwater management objectives include:

- Preventing soil erosion and increases in nonpoint pollution from development projects;
- Preventing stormwater impacts rather than having to mitigate them;
    - Minimizing the extent of land disturbance and impervious surfaces;

  - Minimizing pollutants in stormwater runoff from new development and redevelopment;
  - Restoring, enhancing, and maintaining the chemical, physical, and biological integrity of receiving waters to protect public health and enhance domestic, municipal, recreational, industrial and other uses of water;
  - Aiming to maintain 100% of the average annual pre-development groundwater recharge volume;
  - Capturing and treating stormwater runoff to remove pollutants;
  - Implementing a channel protection strategy to protect receiving streams;
  - Preventing increases in the frequency and magnitude of out-of-bank flooding from large, less frequent storms;
  - Protecting public safety through the proper design, construction and operation of stormwater management facilities;
- Managing stormwater (quantity and quality) as close to the point of origin as possible and minimizing the use of large or regional-scale collection and conveyance facilities;
- Preserving natural areas and native vegetation and reducing the impact on watershed hydrology;
- Using simple, nonstructural methods for stormwater management that are lower in cost and have lower maintenance needs than structural controls;
- Creating a multifunctional landscape; and
- Using natural drainage pathways (the site's hydrology) as a framework for site design.

6.3. THE BENEFITS OF ENVIRONMENTAL SITE DESIGN

Many Virginia communities are currently struggling with the issue of balancing economic growth with protection of their natural resources and water quality. As stated earlier, the rise in impervious cover associated with new development affects local water resources by reducing the infiltration of rainfall and increasing the volumes of stormwater runoff that eventually enter local water bodies. The application of environmental design principles can help developers and local governments recognize increased economic and environmental benefits through reduced infrastructure requirements, decreased need for clearing and grading of sites, and less expenditure to meet stormwater management requirements due to reduced runoff volumes and pollutant export from sites.

There is a common misconception that ESD and LID are more expensive to implement than conventional stormwater management techniques. This derives from the fact that the conventional method of costing stormwater facilities (in the same manner as ponds or centralized facilities) is no longer valid. Environmental site design and LID cause us to rethink how we place value and calculate the cost-benefit of environmental protection.

Communities are asking different costing questions, such as what happens at the end of a 50-year cycle for a pond, or how long can we expand or protect our stormwater infrastructure capacity using grey and green techniques. For example, ten years ago vegetated roofs were thought to be cost-prohibitive to use here in the United States. Yet, as of this writing, at least several North American cities (e.g., Toronto, Chicago, Portland) have built over a hundred vegetated roofs each, while several European cities have already place vegetated roofs on about 15 percent of all buildings. The performance-based technology market-driven approach used by ESD and LID has helped to drive the costs down to the point where they can compete with conventional stormwater management technologies. In many cases, these approaches are proving to have less net cost than conventional stormwater controls. For example, see the document entitled *Reducing Stormwater Costs Through Low Impact Development (LID) Strategies and Practices*, published by the U.S. Environmental Protection Agency, available at www.epa.gov/nps/lid .

There is also a common misconception that ESD and LID practices are difficult to maintain. In reality, if you look at performance record of runoff reduction practices (e.g., bioretention cells, permeable pavement, and vegetated roofs) where they haven't been adequately maintained, they still have a high level of pollutant removal and runoff reduction efficiency. This is important in an era when routine inspection and maintenance is often not performed. Furthermore, ESD and LID practices constitute a distributed management approach, inherently building redundancy into the system. Therefore, if some of the systems perform less than optimally, fail, or are not maintained, redundant decentralized practices at the site prevent the effect from being catastrophic, as with dam breaches or system overloads.

Several researchers have employed redesign comparisons to demonstrate the benefits of environmental site design over a wide range of residential lot sizes and commercial applications. For example, Center for Watershed Protection (CWP, 1998b) demonstrated that ESD techniques could reduce impervious cover and stormwater runoff by 7 to 70 percent, depending on site conditions. **Figure 6.2** below illustrates a redesign analysis for a medium density residential subdivision. The analysis suggested that ESD techniques could reduce impervious cover and annual runoff volume by 24%, cut phosphorus loadings by half, and increase site infiltration by 55%, compared to a traditional subdivision.

In another analysis (CWP, 2003), the CWP evaluated the application of environmental design techniques to development projects in several Virginia localities. The following are examples of the economic benefits that can be gained through encouraging the use of environmental design techniques:

- For a 45-acre medium density residential site in Stafford County, Virginia, using environmental site design techniques would have saved $300,547 compared to a more conventional design, due to reduced infrastructure and stormwater costs (CWP, 1998b).
- Studies have found that construction savings can be as much as 66 percent by using the open space designs encouraged in environmental site design techniques (CWP, 1998a).
- Environmental site design can also reduce the need to clear and grade 35-60 percent of the total site area. Since the total cost to clear, grade, and install erosion and sediment control practices can range up to $5,000 per acre, reduced clearing can result in significant cost savings to builders (Schueler, 1995).
- A summary of 40 years of fiscal impact studies showed that smart growth consumes 45 percent less land, costs 25 percent less for roads, 15 percent less for utilities, 5 percent less for housing, and 2 percent less for other fiscal impacts than current trends of sprawl development (Burchell and Listokin, 1995).
- A 1990 study for the City of Virginia Beach compared the costs and benefits of conventional and smart growth development patterns. The study found that the smart growth pattern resulted in 45 percent more land preserved, 45 percent less in infrastructure costs to the city,

and a 50 percent reduction in impervious surfaces due to roads (Siemon, Larsen and Purdy, et al., 1990)

Figure 6.2. Comparative Analysis of Stonehill Estates in the Pre-development Condition (top), the Conventional Design (middle), and the Open-Space Design (bottom)
Source: Center for Watershed Protection (1998)

To illustrate the economic advantages of environmental site design, **Table 6.1** provides a short summary of the environmental cost benefits realized for four development projects in Virginia that have applied a number of Model Development Principles advocated by the Center for Watershed Protection (CWP, 2000b).

Table 6.1. Benefits of Environmental Site Design vs. Convention Development: 4 Virginia Studies

Case Study	Percent of Natural Areas Conserved	Percent Reduction in Impervious Cover	Percent Reduction in Stormwater Impacts			Percent Reduction in Total Infrastructure Cost
			Runoff	N Load	P Load	
Fields at Cold Harbor Hanover County, VA	80.4	25.3	12.2	6.4	6.4	47.2
Governor's Land James City County, VA	49.3	21.7	14.3	17.5	17.3	14.5
Rivergate Alexandria, VA	0*	32	30	25	28	49
The Arboretum III Chesterfield County, VA	5.1	12	19.7	36	37.1	Not calculated
* Open space area is maintained as landscaped parkland						

Source: CWP (2000b) and the James River Association

The assessment of Model Development Principle application in Virginia found that for the three residential case studies, the use of environmental site design could save up to 49 percent in total infrastructure costs, compared to conventional development (CWP, 2000b). Estimated total infrastructure costs include the costs of roads, gutters, sidewalks, landscaping, and stormwater control practices. In all these cases, the designs incorporating environmental site design saved the developers more than $200,000 in infrastructure costs, while producing the same number of housing units.

In addition, other more intangible economic benefits that may be derived from the use of environmental site design techniques are not included in the case studies. Environmental site design techniques continue to provide benefits to the community beyond improving water quality and stormwater runoff management that extend long after the developer has sold the lots. Some examples of these benefits include:

- Reduced operation and maintenance costs for roads and stormwater system
- Increased property values for homes and businesses
- Increased open space available for recreation
- More pedestrian friendly neighborhoods
- Reduced annual cost for mowing
- Protection of sensitive forests, wetlands, and habitats
- More aesthetically pleasing and naturally attractive landscapes
- Improved air quality (more forest cover)
- Less temperature fluctuation from paved surfaces
- Reduced heating and cooling costs for homeowners from tree preservation

- Decreases in flooding incidence and associated damage
- Improved pollutant removal from the filtering action of forest and stream buffer areas.

For a more detailed summary, consult *The Economic Benefits of Protecting Virginia's Streams, Lakes, and Wetlands,"* prepared by the Center for Watershed Protection. Studies have found that developments that permanently protect open space are often more desirable to live in, and consequently have higher property values (CWP, 1998a). **Table 6.2** illustrates the cost savings for both local governments and developers associated with using environmental site design, most of which are related to infrastructure, maintenance, and stormwater-related costs.

Table 6.2. Percent Savings Due to Compact Growth Patterns (1992 – 1997)

Area of Impact	Lexington, KY and Delaware Estuary	Michigan	South Carolina	New Jersey
Infrastructure Roads	14.8 – 19.7	12.4	12	26
Utilities	6.7 – 8.2	13.7	13	8
Developable Land Preservation	20.5 – 24.2	15.5	15	6
Agricultural Land Preservation	18 – 29	17.4	18	39

(Source: Burchell et al., 1998)

In summary, each environmental site design technique provides environmental and economic benefits to both the developer and the community at large. When techniques are applied together at a development site, they can result in tangible savings for the developer in the form of:

- Reduced construction (e.g., clearing and grading) costs;
- Reduced infrastructure costs (e.g., paving and piping)
- Smaller and less costly structural stormwater BMPs
- Faster sales and lease rates
- Easier compliance with wetland and other resource protection regulations
- More land available for building since fewer structural BMPs are needed
- Credits toward LEED™ certifications.

Cost savings really start to add up when many ESD techniques are applied together. Research indicates that infrastructure savings alone can range from 5-65%, depending on site conditions, lot size and the extent that ESD techniques are applied (Cappiella et al, 2005; CWP, 1998b; Liptan and Brown, 1996; Dreher and Price, 1994; and Maurer, 1996). **Table 6.3** below compares the economic and environmental benefits that can be expected for individual environmental site design techniques.

Table 6.3. Comparison of Benefits of Environmental Site Design Techniques*

Environmental Site Design Technique	Minimizes Land Disturbance	Preserves Vegetation & Habitat	Lowers Capital Costs	Lowers O&M ** Costs	Raises Property Value
Preserve Undisturbed Natural Areas	○	○	○	○	◖
Preserve Riparian Buffers	○	○	○	○	◖
Preserve and Plant Trees	◖	○	●	○	○
Avoid Floodplains	○	○	○	○	◖
Avoid Steep Slopes	○	○	○	○	◖
Fit Design to the Terrain	○	◖	○	○	○
Locate Development in Less Sensitive Areas	◖	◖	○	○	◖
Reduce Limits of Clearing and Grading	○	○	○	◖	◖
Use Open Space Development	○	○	○	○	◖
Consider Creative Development Design	○	○	◖	◖	◖
Reduce Roadway Lengths and Widths	○	◖	○	○	◖
Reduce Building Footprints	◖	◖	○	○	◖
Reduce the Parking Footprint	◖	◖	○	○	◖
Reduce Setbacks and Frontages	◖	◖	◖	◖	◖
Use Fewer or Alternative Cul-de-Sacs	◖	◖	○	○	◖
Create Parking Lot Stormwater Islands	◖	◖	◖	◖	◖
Use Buffers and Undisturbed Areas (for SWM)	○	○	○	○	◖
Use Natural Drainageways Versus Storm Sewers	◖	◖	○	◖	◖
Use Vegetated Swales Versus Curb & Gutter	◖	◖	○	◖	◖
Drain Runoff to Pervious Areas	◖	◖	○	○	◖
Infiltrate Site Runoff or Capture It for Reuse	◖	◖	○	◖	◖
Stream Daylighting for Redevelopment Projects	●	○	◖	◖	◖

Key: ○ = Often provides indicated benefit
◖ = Sometimes provides a modest benefit
● = Does not provide benefit

* Comparison is intended for general purposes and will vary on a site-by-site basis
** O&M = Operation and Maintenance

Source: Adapted from MPCA (2006)

6.4. ENVIRONMENTAL SITE DESIGN PROCESS

As noted in **Section 6.1.1.2**, site design should be done ***in unison with*** the design and layout of stormwater infrastructure in attaining stormwater management and land use goals. Key concepts in ESD parallel requirements of state and federal wetland permitting programs, as follows:

- ***Avoid*** the Impacts – Use environmental site design techniques to preserve natural features and fit the site design to the natural terrain and natural features (see **Figure 6.3** below)
- ***Minimize*** (or *reduce*) the Impacts – Reduce mass grading and impervious cover.
- ***Mitigate*** (or *manage*) the Impacts – Use natural features and Environmental Site Design techniques to manage stormwater

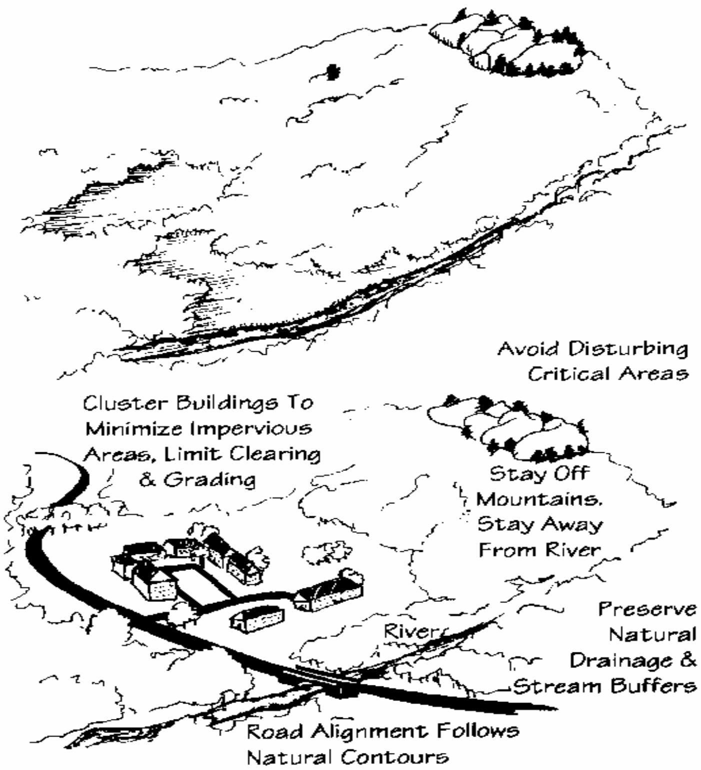


Figure 6.3. Fit the Site Design to the Natural Terrain and Natural Features
Source: CNMI and Guam Stormwater Management Manual (2006)

Once sensitive resource areas and site constraints have been avoided, the next step is to minimize the impact of land alteration by reducing mass grading and the amount of impervious surfaces. Finally, for the areas that must be impervious, choose alternative and "natural-systems" stormwater management techniques as opposed to the more conventional structural ("pipe-to-pond") approach. The goal is to disconnect runoff from impervious surfaces and promote filtration, infiltration and on-site use that mimics the pre-development hydrologic regime of the site and minimizes harmful impacts on the streams that receive runoff discharge from the site.

The aim is to reduce the environmental "footprint" of the site while retaining and enhancing the owner/developer's purpose and vision for the site. Many of the ESD concepts can reduce the cost of infrastructure while maintaining or even increasing the value of the property, especially when incorporated early into the site design. For example, **Figure 6.4** below is a map representing a natural resource inventory of a 15-acre development site. **Figure 6.5** below is a more traditional plan layout for this site, with 25 lots, each exceeding ½-acre in area. A more traditional subdivision street design is used, with curb-and-gutter configuration draining into underground storm sewers. Minimal stream buffers and natural areas have been preserved. Much of the original vegetation from the site would have to be removed during the grading process. Using the Virginia Runoff Reduction Method Spreadsheet to calculate water quality treatment requirements for this site, we would calculate a required runoff "Treatment Volume" of 18,100 cubic feet. This is the volume of runoff that would have to be captured by BMPs and treated to remove the necessary amount of pollutants in order to comply with the water quality requirements in the Virginia SWM Regulations.

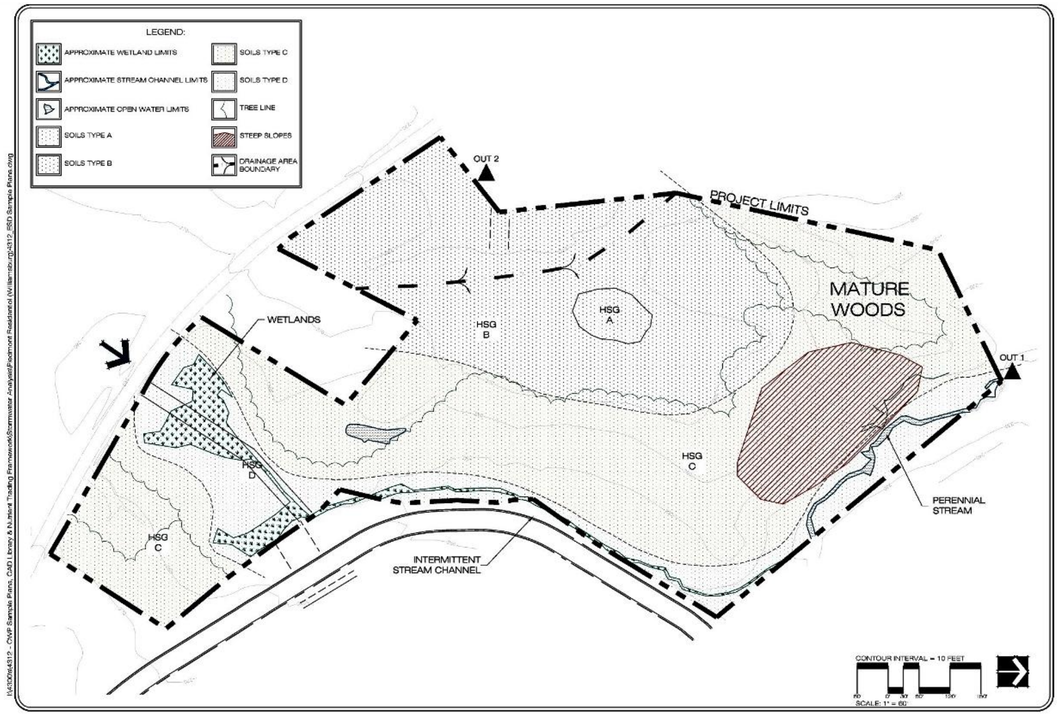


Figure 6.4. Natural Resource Inventory Site Map
Source: Center for Watershed Protection

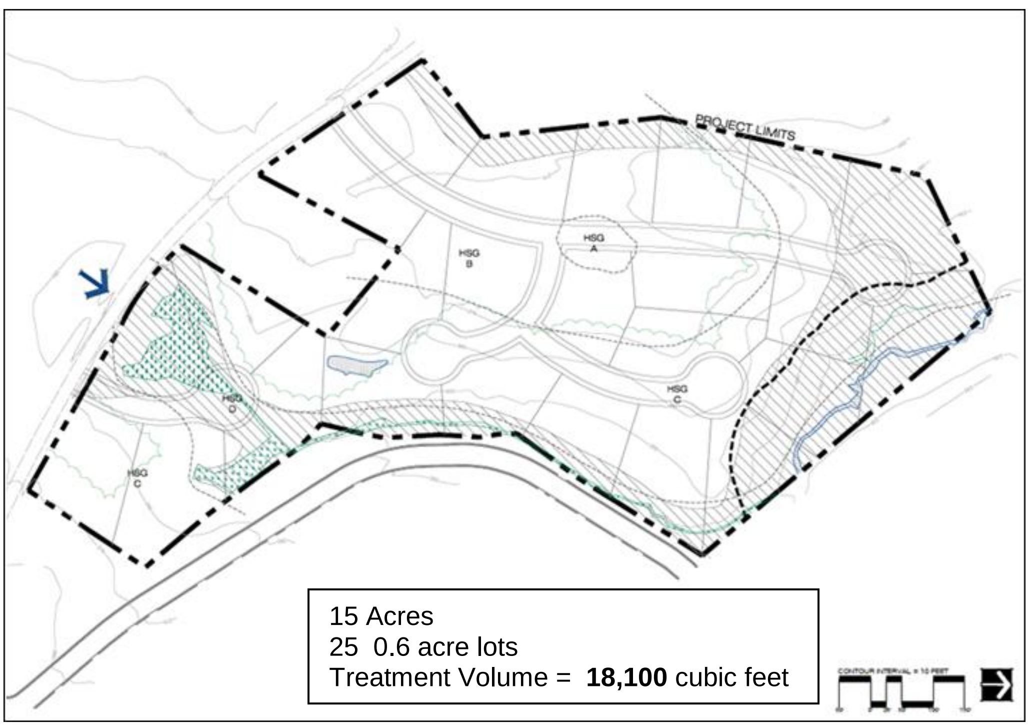


Figure 6.5. Traditional Site Plan
Source: Center for Watershed Protection

By contrast, **Figure 6.6** reflects the application ESD techniques. Smaller ¼-acre lots are clustered in a tighter configuration on the site. The streets are narrower and shorter, minimizing impervious cover, and the streets drain to surface swales that allow for runoff filtering and infiltration. More of the site's original vegetation is conserved as buffers or other open space, which also reduces the amount of stormwater runoff. When we apply the Spreadsheet to this alternative design, we calculate a runoff Treatment Volume of only 14,300 cubic feet. **That is a 25% reduction in the amount of runoff that must be treated and a smaller pollutant reduction requirement (due to less pollutants being generated in runoff from the site), achieved simply by applying Environmental Site Design techniques alone, *before* any stormwater management BMPs have been chosen and applied to the site.**

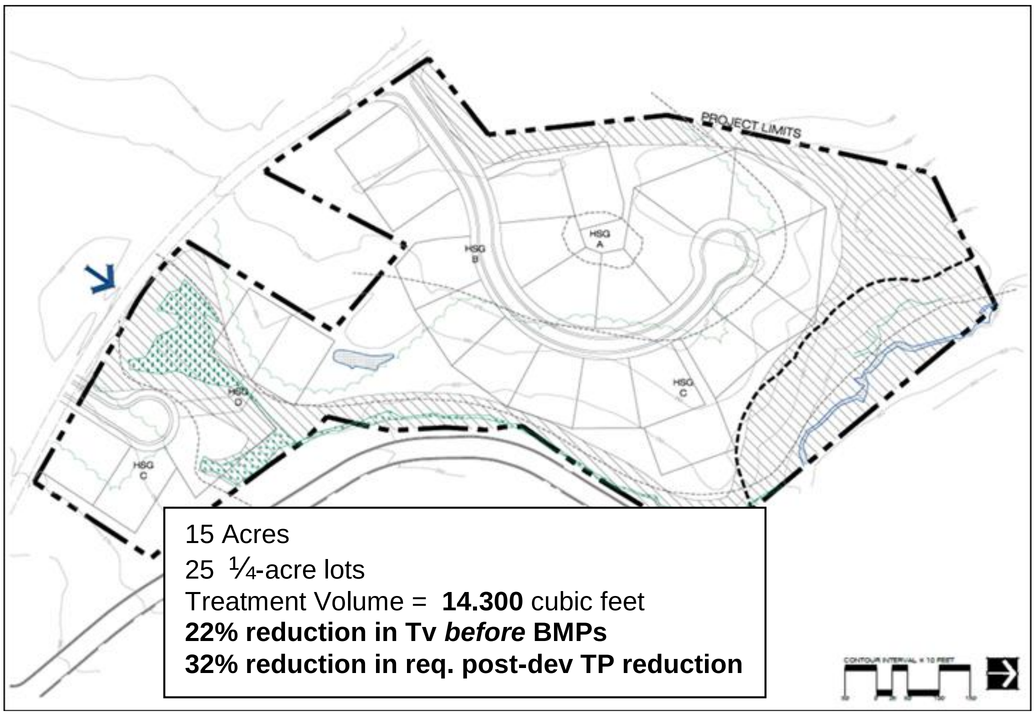


Figure 6.6. Contrasting Environmental Site Design for the Same Site
Source: Center for Watershed Protection

Reduction of adverse stormwater runoff impacts through the use of Environmental Site Design should be the first consideration of the design engineer. Operationally, economically, and aesthetically, the use of Environmental Site Design techniques offers significant benefits over treating and controlling runoff downstream. Therefore, all opportunities for using these methods should be explored and all viable options exhausted before considering the use of structural stormwater controls.

The use of Environmental Site Design typically results in a reduction of the required runoff peak flows and volumes that need to be conveyed and controlled on a site and, therefore, the size and cost of necessary drainage infrastructure and structural stormwater controls. In some cases, the use of Environmental Site Design practices may eliminate the need for structural controls entirely. Hence, Environmental Site Design concepts can be viewed as both a water quantity and water quality management tool.

6.4.1. Environmental Site Design Site Planning Checklist

The following checklist (**Table 6.4** below) is provided to help site designers ensure that they do *not* overlook any opportunities to integrate ESD into their site plans. The list includes 12 criteria that cover the main concepts addressed by ESD. Ideally, a designer should be able to answer "Yes" or "Does Not Apply" (N/A) to every criterion. If a designer answers "No" to any of the criteria, he should give careful consideration to the reasons why the criteria cannot be applied to the site.

Table 6.4. Environmental Site Design Checklist Example

Check All of the Following ESD Practices That Were Implemented On-Site	Yes	No	N/A
Environmental mapping was conducted at the site prior to layout	X		
Natural areas were conserved (e.g., forests, wetlands, steep slopes, floodplains)	X		
Stream, wetland and shoreline buffers were reserved			X
Disturbance of permeable soils was minimized	X		
Natural flow paths were maintained across the site	X		
The building layout was footprinted to reduce clearing and grading at the site	X		
Site grading promotes sheetflow from impervious areas to pervious areas	X		
Site design was evaluated to reduce creation of unnecessary impervious cover	X		
Site design was evaluated to maximize the disconnection of impervious cover	X		
Site design was evaluated to identify potential hotspot generating areas for stormwater treatment	X		
Erosion and sediment control practices and post-construction stormwater management practices were integrated into a comprehensive site plan	X		
Tree planting was used at the site to convert turf areas into forest	X		

Source: Chesapeake Bay Stormwater Training Partnership

6.4.2. List of Stormwater Environmental Site Design Techniques and Practices

The stormwater-related ESD practices and techniques covered in this Handbook are grouped into four categories and are listed below:

A. Conserving of Natural Features and Resources

1. Preserve Undisturbed Natural Areas
2. Preserve Riparian Buffers
3. Preserve or Plant Trees
4. Avoid Floodplains
5. Avoid Steep Slopes

B. Using Lower Impact Site Design Techniques

6. Fit Design to the Terrain
7. Locate Development in Less Sensitive Areas
8. Reduce Limits of Clearing and Grading
9. Utilize Open Space Development
10. Consider Creative Development Design

C. Reducing Impervious Cover in Site Design

11. Reduce Roadway Lengths and Widths
12. Reduce Building Footprints
13. Reduce the Parking Footprint
14. Reduce Setbacks and Frontages
15. Use Fewer or Alternative Cul-de-Sacs
16. Create Parking Lot Stormwater "Islands"

D. Using Natural Features and Runoff Volume Reduction for Stormwater Management

17. Use Buffers and Undisturbed Filter Areas
18. Use Creative Site Grading, Berming and Terraforming
19. Use Natural Drainageways and Vegetated Swales, Not Storm Sewers/Curb & Gutter
20. Drain Rooftop Runoff to Pervious Areas
21. Infiltrate Site Runoff or Capture It for Reuse
22. Stream Daylighting for Redevelopment Projects

More detail on each site design practice is provided in the Environmental Site Design Practice Summaries in the next section of this chapter. These summaries provide the key benefits of each practice, examples and details on how to apply them in site design.

6.4.3. Using Stormwater Environmental Site Design Practices

Site design should be done in unison with the design and layout of stormwater infrastructure in attaining stormwater management goals. The following bullets describe the stormwater-related ESD process that use the four ESD categories:

- Identify existing natural features and resources and delineate site conservation areas
- Design the site layout to preserve conservation areas and minimize stormwater impacts
- Use various techniques to reduce impervious cover in the site design
- Use natural features and conservation areas to manage stormwater quantity and quality

The first step in stormwater-related ESD involves identifying significant natural features and resources on a site such as undisturbed forest areas, stream buffers and steep slopes that should be preserved to retain some of the original hydrologic function of the site.

Next, the site layout is designed such that these conservation areas are preserved and the impact of the development is minimized. A number of techniques can then be used to reduce the overall imperviousness of the development site.

Finally, natural features and conservation areas can be utilized to serve stormwater quantity and quality management purposes.

6.5. ENVIRONMENTAL SITE DESIGN TECHNIQUES AND PRACTICES

6.5.1. Conserving Natural Features and Resources

Conservation of natural features is integral to environmental site design. Natural areas generate the least amount of stormwater runoff and pollutant loads and establish and maintain the desired pre-development hydrology for the site. The first step in the ESD process is to identify and preserve the natural features and resources that can be used in the protection of water resources by reducing stormwater runoff, providing runoff storage, reducing flooding, preventing soil erosion, promoting infiltration, and removing stormwater pollutants. Next, designers modify the layout of the development project to take advantage of natural features, preserve the most sensitive areas, and mitigate any stormwater impacts. Open space design is one of the most effective environmental site design techniques for preserving natural areas at residential sites without losing developable lots. Some of the natural features that should be taken into account include the following:

- Perennial streams
- Intermittent and ephemeral streams
- Zero order streams
- Springs and seeps
- Aquifer recharge areas
- Riparian stream buffers
- Wetlands/tidal marshes
- Wetland buffers
- Floodplains
- Existing drainage areas and drainage divides
- Forest stands
- Other significant vegetative cover
- Ridge tops and steep slopes
- Sinkholes, caves and other karst features
- Highly erodible soils
- Highly permeable soils
- Shallow bedrock
- High water tables
- Other critical areas

Delineation of natural features is typically done through a comprehensive site analysis and inventory before any site layout design is performed. From this site analysis, a concept plan for a site can be prepared that provides for the conservation and protection of natural features. **Figures 6.7 and 6.8** below show how to use GIS map layers to delineate natural features on a parcel's base map and, from that information, develop a composite site resource map.

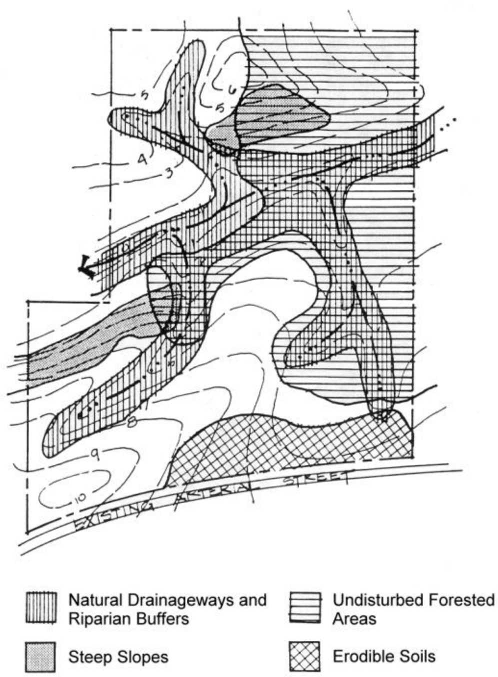


Figure 6.7. Map Delineating Natural Feature on a Site
Source: MPCA (1989)

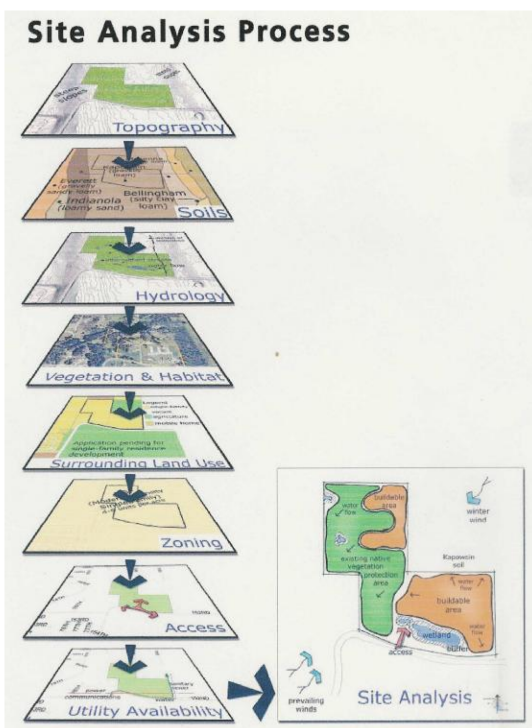


Figure 6.8. A Composite Map Developed from GIS Map Layers
Source: Puget Sound LID Technical Manual (2005)

6.5.1.1. Environmental Site Design Practice #1: Preserve Undisturbed Natural Areas

KEY BENEFITS	USING THIS PRACTICE
• Conserving undisturbed natural areas helps to preserve a portion of the site's natural predevelopment hydrology • Can be used as nonstructural stormwater filtering and infiltration zones • Helps to preserve the site's natural character and aesthetic features • May increase the value of the developed property	• Delineate natural areas before performing site layout and design • Ensure that conservation areas and native vegetation are protected in an *undisturbed state* throughout construction and occupancy

Figure 6.9. A Subdivision with Conserved Natural Areas

Clearing and grading of native vegetation should be limited to the minimum needed to (1) build on lots, (2) allow access, and (3) provide fire protection. Important natural features and areas such as undisturbed forested and vegetated areas, natural drainageways, stream corridors, wetlands and other important site features should be delineated and placed into conservation areas. A suggested limit of disturbance (LOD) is 5 to 10 feet out from building pads (**Figure 6.10** below).

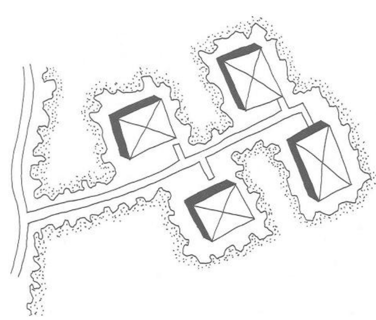


Figure 6.10. Site Footprinting
Source: Center for Watershed Protection

Preserving such areas on a development site helps to preserve the original hydrology of the site and aids in reducing the generation of stormwater runoff and pollutants. Undisturbed vegetated areas also promote soil stabilization and provide for filtering, infiltration and evapotranspiration of runoff.

Natural conservation areas are typically identified through a site analysis using maps and aerial/satellite photography, or by conducting a site visit. These areas should be delineated before any site design, clearing or construction begins. When done before the concept plan phase, the planned conservation areas can be used to guide the layout of the site. **Figure 6.11** shows a site map with undisturbed natural areas delineated.

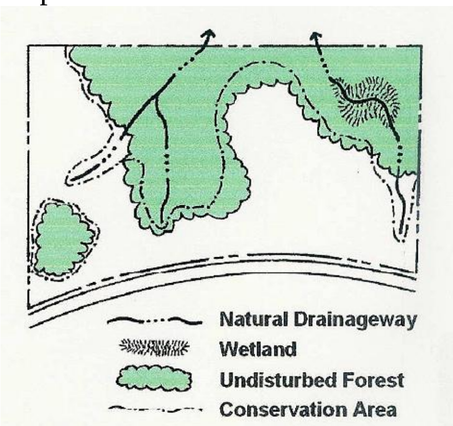


Figure 6.11. Delineation of Natural Conservation Areas
Source: ARC (2006)

Conservation areas should be incorporated into site plans and clearly marked on all construction and grading plans to ensure that equipment is kept out of these areas and that native vegetation is not undisturbed. The boundaries of each conservation area should be mapped to illustrate the limit which should not be crossed by construction activity. Once established, natural conservation areas must be protected during construction and managed after occupancy by a responsible party able to maintain the areas in a natural state in perpetuity. Typically, conservation areas are protected by legally enforceable deed restrictions, conservation easements, and maintenance agreements. Buildings and roads should be located *around* the natural topography and drainage to avoid unnecessary land disturbance.

The undisturbed soils and vegetation of natural areas promote infiltration, runoff filtering and direct uptake of pollutants. Forested areas intercept rainfall in their canopy, reducing the amount of rain that reaches the ground. Vegetation also pumps soil water back into the atmosphere which increases storage available in the soil. Native vegetation also prevents erosion by stabilizing soil, filtering sediment and pollutants from runoff, and absorbing nutrients from the soil and groundwater.

Wetlands provide many benefits to society, including habitat for fish and wildlife, natural water quality improvement, flood storage, shoreline erosion protection, and opportunities for recreation and aesthetic appreciation. Wetlands are among the most productive and biodiverse ecosystems in the world – comparable to rain forests and coral reefs (EPA, 2007c). Estuaries and their coastal marshes are important nursery areas for the young of many game (recreational) and commercial fish and shellfish.

Wetlands help improve water quality, including that of drinking water, by intercepting surface runoff and removing or retaining inorganic nutrients, processing organic wastes, and reducing suspended sediments before they reach open water. Furthermore, a large part of recreational bird-watching – an outdoor recreational activity that is growing in popularity even faster than biking, walking, skiing or golf – is associated with wetlands and aquatic habitats, in large part because many birds are wetland-dependent.

Preserving areas where threatened or endangered species exist is also a wise decision and is typically required by law. As frustrating as this may seem to landowners and developers, there are good scientific reasons to preserve the habitat of these species. Species extinctions can disrupt the interactions and feedback mechanisms of natural ecosystems that have developed over time to be relatively stable and resistant to pests and diseases. Stable natural ecosystems control more than 95 percent of the potential crop pests and carriers of human diseases (Erlich, 1985).

Invasive species compete with and harm plant and animal communities and disrupt natural ecosystems. Some 5,000 plant species have escaped into natural ecosystems, resulting in millions of dollars in control costs (Pimentel et al., 2005). Invasive species on the site should be identified when the development site is initially assessed. Then, as the development area is being cleared, effort could be made to remove any invasive species present. Such actions could help to methodically reduce or remove invasive species from an area or region.

A point that is often not considered during the planning of a development project and the preservation of natural open space on the development site is reducing the risk of catastrophic wildfire. Designing defensible space around structures protects property from wildfire damage by reducing flame heights and making fires easier to extinguish (Firewise Communities). When fuel loads exceed historical conditions, high intensity fires are more likely to occur, causing significant ecological damage (see SAFC). Design that takes into consideration reduction and management of fuels on the site reduces risks to local ecosystems, property and lives.

Where vegetation must be established on the site, choose to restore appropriate plants and plant communities that are native to the ecoregion of the site, to contribute to regional diversity of flora and provide appropriate habitat for native wildlife. Native plants provide habitat for native wildlife, including important pollinator species (e.g., insects, birds and bats) that are necessary for plant reproduction, including cultivation of nearby crops. Up to 80 percent of the world's food plant species are dependent on pollination by animals (Buchman and Nabhan, 1996). Wildlife habitat also supports recreational and educational opportunities.

As discussed in **Section 6.4.3** above, there are many environmental and economic reasons to establish native trees rather than lawn areas that require more intensive management, especially in open space to be conserved on the site. Not the least of these reasons is minimizing the application of chemical fertilizers and pesticides needed to maintain the desired appearance health and appearance of turfgrass.

Preserving natural areas creates many economic benefits including decreased heating and cooling costs, higher property values and improved habitat (Cappiella, 2005). To approach full ecological function, it is recommended that natural grassland areas should be five acres or larger and a forested areas should be in the range of 20-40 acres. However, smaller areas will still yield water quality and other environmental benefits. When there is not enough conserved area on the development site to meet these thresholds, the designer should attempt to connect on-site conservation areas with similar areas off-site.

Leadership in Energy and Environmental Design (LEED®) and the Sustainable Sites Initiative (SSI). The LEED® point credit system designed by the U.S. Green Building Council (USGBC) and implemented by the Green Building Certification Institute (GBCI) awards points related to site design and stormwater management. Several categories of points are potentially available for new development and redevelopment projects. The SSI point credit system was designed by the American Society of Landscape Architects (ASLA) and the Lady Bird Johnson Wildflower Center at the University of Texas at Austin, and the National Botanic Garden (see ASLA et al., 2009a and 2009b). **Appendix 6-D** of this Chapter provides a more thorough discussion of the site planning process and design considerations as related to SSI credits. It is anticipated that SSI credits may eventually be blended into LEED credits. However, DEQ is not affiliated with any of the creators of LEED or SSI, and any information on applicable points suggested here is based only on perceived compatibility. **Designers should research and verify scoring criteria and applicability of points as related to the specific project being considered through LEED or SSI resources.**

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
1.3: Preserve wetlands	0 (Prerequisite)
1.4: Preserve threatened and endangered species	0 (Prerequisite)
4.1: Control and manage known invasive plants found on the site	0 (Prerequisite)
4.8: Preserve plant communities native to the ecoregion	2 - 6
4.9: Restore plant communities native to the ecoregion	1 - 5
4.13: Reduce the risk of catastrophic wildfire	3

6.5.1.2. Environmental Site Design Practice #2: Preserve Riparian Buffers

KEY BENEFITS	USING THIS PRACTICE
• Riparian buffers can be used as nonstructural stormwater filtering and infiltration zones • Keeps structures out of the floodplain and provides a right-of-way for large flood events • Helps to preserve riparian ecosystems and habitats	• Delineate and preserve naturally vegetated riparian buffers • Ensure that buffers and native vegetation are protected throughout construction and occupancy • Consult the local plan review authority for applicable buffer requirements and minimum or recommended widths
This practice reflects the CWP Better Site Design Principles #17 (Buffer Systems) and #18 (Buffer System Management)	

Naturally vegetated riparian buffers should be delineated and preserved or restored along the shorelines of all perennial streams, rivers, lakes, and wetlands. The primary function of buffers is to protect and physically separate a stream, lake or wetland from future disturbance or encroachment. Given the importance of riparian forests in the ecology of headwater streams, characteristics such as width, target vegetation and allowable uses within the buffer should be managed to ensure that the goals designated for the buffer are achieved.

Buffers are not merely setbacks, but vegetated systems managed to protect targeted soil and water resources. If properly designed, a buffer can stabilize soils, provide stormwater management functions, provide a right-of-way during floods, and sustain the integrity of stream ecosystems, wildlife corridors and habitats. An example of a riparian stream buffer is shown in **Figure 6.12**. Improved water quality resulting from riparian buffers can increase property values of waterside properties by up to 15 percent (Braden and Johnston, 2004). Riparian forest buffers should be maintained, and reforestation with native species should be encouraged where no wooded buffer exists. Proper restoration should include not just trees all layers of the forest plant community, including understory, shrubs and groundcover,. A riparian buffer can be of fixed or variable width, but should be continuous and not interrupted by impervious areas that allow stormwater to concentrate and flow into the stream without first flowing through the buffer.

Figure 6.12. Riparian Stream Buffer
Source: Center for Watershed Protection

Ideally, riparian buffers should be sized to include the 100-year floodplain as well as steep banks and freshwater wetlands. For proper performance, buffer depth will depend on the size of the stream and the surrounding conditions; but a minimum 25-35 foot undisturbed vegetative buffer is needed for even the smallest perennial streams and a 50-foot or larger undisturbed buffer is ideal. Even with a 25-35 foot undisturbed buffer, additional zones can be added to extend the total buffer to at least 100 feet from the edge of the stream (100 feet in Chesapeake Bay Preservation Areas). The three distinct zones are shown in **Figure 6.13** below.

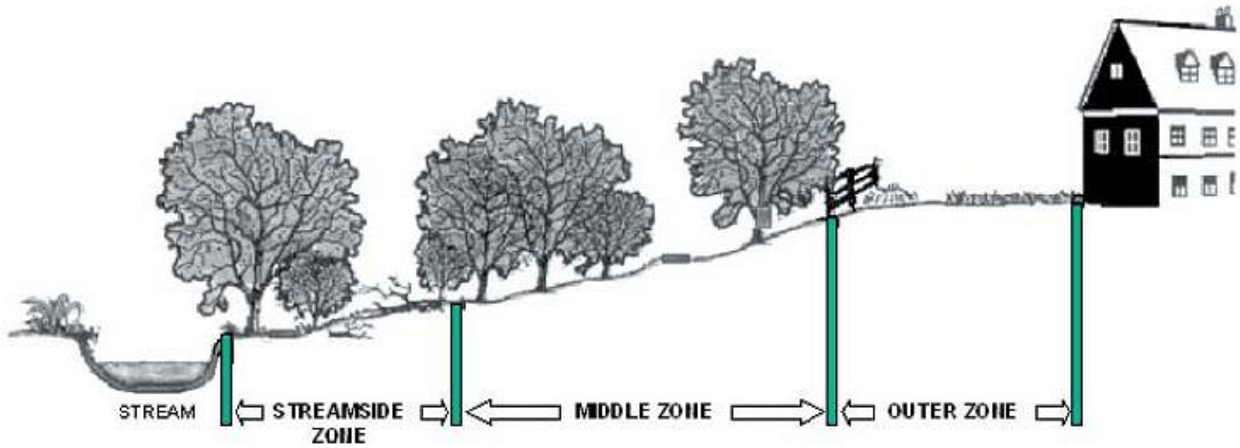


Figure 6.13. Three-Zone Stream Buffer System
Source: CWP (1998a)

The buffer is often viewed as simply a line drawn on a map that is virtually invisible to contractors and landowners. In order to increase awareness of the buffer and the need for its protection, the boundaries should be marked with appropriate signage. Local governments may provide such signage. Some localities also implement buffer awareness programs and literature for their citizens.

To optimize stormwater treatment, the outer boundary of the buffer should have a stormwater depression area and a grass filter strip. Runoff captured within the stormwater depression is spread across a grass filter designed for sheet flow conditions, and discharges to a wider forest or shrub buffer in the middle or streamside zones that can fully infiltrate and/or further treat storm flow. The function, vegetative target and allowable uses vary by zone as described in **Table 6.5**.

Table 6.5. Riparian Buffer Management Zones

Criteria	Streamside Zone	Middle Zone	Outer Zone
Width	Minimum 25 feet plus wetlands and critical habitat (35 feet is better for both forest and wildlife habitat); protect the physical integrity of the stream ecosystem.	Variable, depending on stream order, slope, and extent of 100-year floodplain (min. 25 feet, but generally 50-75 feet); provides a buffer between upland development and the streamside zone.	25-foot minimum setback from structures; prevent encroachment and filter backyard runoff.
Vegetative Cover	Undisturbed mature forest. Reforest, if grass.	Managed forest, with some clearing allowed.	Forest encouraged, but usually turfgrass.
Allowable Uses	**Very Restricted** e.g., flood control, utility easements, rights-of-way, footpaths, limited water access, trimming for sight lines.	**Restricted** e.g., some passive recreational uses, some stormwater controls, pedestrian and bike paths, tree removal by permit.	**Unrestricted** e.g., residential uses including lawn, garden, compost, yard wastes, and most stormwater controls.

Source: MPCA (2006)

These recommendations are minimum criteria that should apply to most streams. Some streams and watersheds may require additional measures to achieve protection. In some areas, specific laws and regulations (e.g., the Chesapeake Bay Preservation Act) or local ordinances (e.g., drinking water reservoir protection) may require stricter buffers than are described here. The buffer widths discussed herein are not intended to modify or supersede deeper or more restrictive buffer requirements that are already in place.

As stated above, the streamside or inner zone should consist of a minimum of 25-35 feet of undisturbed mature forest. In addition to runoff protection, this zone provides bank stabilization as well as shading and protection for the stream. This zone should also include wetlands and any critical habitats, and its width should be adjusted accordingly. The middle zone provides a transition between upland development and the inner zone and should consist of managed woodland that allows for infiltration and filtration of runoff. An outer zone allows more clearing and acts as a further setback from impervious surfaces. It also functions to prevent encroachment and filter runoff. It is here that flow into the buffer should be transformed from concentrated flow into sheet flow to maximize ground contact with the runoff. Level spreaders can be used to accomplish this.

When establishing or enhancing riparian buffers on a development site, it is important to manage the buffer in a way that reduces the risk of catastrophic wildfire. Increasingly, development is occurring near wildland environments where wildfire is a major element of the native plant community. Development is expanding into the wildland/urban interface where structures are located next to large areas of natural vegetation. Designing defensible space around structures protects property from wildfire damage. Design that takes into consideration reduction and management of fuels on the site reduces risks to local ecosystems, property and lives

A Fire Hazard Rating System and National Wildland/Urban Interface Fire Protection Program has been established, which provides recommendations for target vegetation around structures. **Table 6.6** below presents a rating system for estimating the hazard potential of developing in a wildland/urban interface area. If a community has a high potential risk for wildfire, then it makes sense to consider the vegetation management techniques that are described in **Table 6.7** below. The most common technique is to clear or reduce vegetation that is within 70 feet of structures.

Development within the riparian buffer should be limited only to those structures and facilities that are absolutely necessary. Such limited development should be specifically identified in any codes or ordinances enabling the buffers. When construction activities do occur within the riparian corridor, specific mitigation measures should be required, such as deeper buffers or riparian buffer improvements.

Generally, the riparian buffer should remain in its natural state. However, some maintenance is periodically necessary, such as preventing concentrated flows, removing exotic plant species when these species are detrimental to the vegetated buffer, and removing diseased or damaged trees.

Table 6.6. Sample of Fire Hazard Rating System in the Wildland/Urban Inteface (adapted from the National Wildland/Urban Interface Fire Protection Program) [1]

Hazard Rating Category	Description of Hazard	Point Range	
I. Fuel Hazard Rating [2]	Low, medium or high hazard fuels (grasses, mixed hardwoods, evergreen timber)	Grasses Woodland (open understory) Woodland (heavy brush) Large evergreen timber	1 pt 2-3 pts 4 pts 5 pts
II. Slope Hazard Rating [2]	Mile, moderate, steep, to extreme slopes	Mild slopes (< 5%) Moderate slopes (6-15%) Steep slopes (16-25%) Extreme slopes (> 25%)	1 pt 2 pts 3 pts 4 pts
III. Structure Hazard Rating	Roof and siding material combustibility	Non-combustible roof & siding Non-comb. roof, comb. siding Comb. roof, non-comb. siding Comb. roof & siding	1 pt 3 pts 7 pts 10 pts
IV. Safety Zone Rating [2]	Number of homes that do not have a safety zone of at least 30 feet	30% of homes 31-60% of homes 61-100% of homes	3 pts 6 pts 10 pts
V. Means of Access for Emergency Vehicles [3]	Number of access points or width of access	Only one access point Width for one-way traffic only Road grades > 15% Turn-around inadequate Bridge width limits emrg. equip.	3 pts 3 pts 2 pts 3 pts 3 pts
VI. Additional Factor Rating [3]	Other items that contribute to hazard potential	Most road names not marked Subdiv. Entrance not marked Individual home #s not marked Power lines not buried Lack of mun. water sources Area lacks static water sources Long distance from fire dept. Ease of plowing for fire line	2 pts 2 pts 2 pts 2 pts 2 pts 2 pts 2 pts 1-5 pts

Total Hazard Rating: (0-19 = Low Risk; 20-39 = Medium Risk; 40-60 = High Risk

[1] Total hazard rating is the sum of all points awarded

[2] For Hazard Rating Categories I – IV, assign points based on the one criterion that best describes the existing site conditions.

[3] For Hazard Rating Categories V and VI, points are awarded for all criteria that apply.

Table 6.7. Recommendations for Target Vegetation Around Structures in Medium- to High-Wildfire Areas (adapted from the National Wildland/Urban Interface Fire Protection Program)

Zone	Distance from Combustible Structure	Target Vegetation
A	Primary setback zone – 20 feet	All natural vegetation cleared; plant only low level, fire-resistant vegetation (lawn, low-level ground covers; examples include: lily-of-the-valley, periwinkle, bearberry, lilac)
B	Wet zone – 70 feet	Most natural vegetation removed; area irrigated during dry conditions; planted with low-level, fire-resistant vegetation
C	Thinning zone – 120 feet	Remove all dead/dying vegetation and up to 50% of live natural vegetation (target the most flammable, large foliage, shaggy bark, plants that develop dry or dead undergrowth, etc., for removal)
D	Thinning zone – 150 feet	Remove all dead/dying vegetation and up to 30% of live natural vegetation

Buffers can provide many different ecosystem services and economic benefits, including:

- Reduced small drainage problems and complaints
- Reduced risk of flood damage
- Reduced stream bank erosion
- Enhanced pollutant removal
- Location for greenways and trails
- Sustained integrity of stream ecosystems and habitat
- Protection of wetlands associated with the stream corridor
- Prevention of disturbance of steep slopes
- Mitigation of stream warming
- Protection of important stream corridor habitat for wildlife
- Increased adjacent property values. Some examples of positive market influence include the following:
    - When managed as a "greenway," stream buffers can increase the value of adjacent parcels, as illustrated by several studies. Pannypack Park in Philadelphia is credited with a 33 percent increase to the value of nearby property. A net increase of more than $3.3 million in real estate is attributed to the park (CBF, 1996). Another greenway in Boulder, Colorado was found to have increased aggregate property values by $5.4 million, resulting in $500,000 of additional tax revenue per year (Fausold and Lilieholm, 1996).
    - Homes situated near seven California stream restoration projects had a 3-13 percent higher property value than similar homes located on unrestored streams (Streiner and Loomis, 1996). Most of the perceived value of the restored stream was due to the enhanced buffer, habitat, and recreation afforded by the restoration.
    - Housing prices were found to be 32 percent higher if they were located next to a greenbelt buffer in Colorado (Correll et al., 1978). Nationally, buffers were thought to have a positive or neutral impact on adjacent property in 32 out of 39 communities surveyed (Schueler, 1995).
    - Effective shoreline buffers can increase the value of urban lake property. A recent study in Maine found that water clarity was directly related to property values. Specifically, a measurable improvement in water clarity (visibility depth increased by 3 feet) resulted in $11 to $200 more per foot of shoreline property, potentially generating millions of dollars in increased value per lake (Michael et al., 1996).

The following actions help to minimize the risk of buffer encroachment and damage:

- Make sure buffers appear on site plans and are clearly labeled.
- Make sure buffers also appear on separate clearing and grading plans.
- Identify buffers and discuss buffer protection measures during the pre-construction meeting.
- Make sure construction inspectors assure that buffer integrity is not violated.
- Disclose the presence and location of buffers, with notes regarding limitations of use, on recorded plat maps.
- Implement a local buffer awareness program for citizens.
- Mark buffer boundaries with appropriate signage.

For additional guidance pertaining to planting vegetation in riparian buffer areas, see DEQ's guidance document entitled *Riparian Buffer Modification and Mitigation Guidance Manual*, available at the following website:

http://www.dcr.virginia.gov/chesapeake_bay_local_assistance/ripbuffmanual.shtml.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.3: Protect and restore riparian, wetland, and shoreline buffers	3 - 8
4.13: Reduce the risk of catastrophic wildfire	3

6.5.1.3. Environmental Site Design Practice #3: Preserve or Plant Native Trees

KEY BENEFITS	USING THIS PRACTICE
• Reduce stormwater runoff • Increase nutrient uptake • Stabilize streambanks • Provide shading and cooling • Provide pleasing aesthetic values • Provide or enhance wildlife habitat • Better resist disease and harsh conditions	• Perform an inventory of the existing forest and identify trees to protect. • Design the development with conservation of native vegetation in mind. • Protect designated trees during and after construction. • Plant additional trees and native vegetation at the development site.
This practice reflects the CWP Better Site Design Principle #20 (Tree Conservation)	

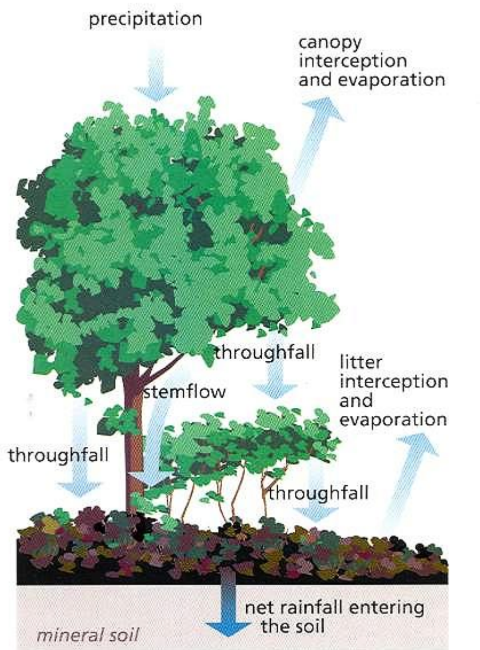


Figure 6.14. The Benefits of Tree Canopy for Stormwater Management

Native trees, shrubs and grasses are important contributors to the overall quality and viability of the environment. One of the most cost-effective ESD practices is to conserve or plant trees and shrubs at new development or redevelopment sites, clustering tree areas and promoting the use of native plants (see contrast in **Figures 6.15 and 6.16** below). Wherever feasible, manage community open space, street rights-of-way, parking lot islands, and other landscaped areas to promote natural vegetation. This reduces stormwater runoff, reduces nutrient pollution (see **Figure 6.17** below), provides streambank stabilization, provides shading and cooling, and provides wildlife habitat (Cappiella, 2005). Forest soils actively promote greater infiltration rates due to surface organic matter and macro-pores created by tree roots. Forests intercept rainfall in their canopy, reducing the amount of rain that reaches the ground and increasing potential water storage in forest environments.

Figure 6.15. Subdivision with Tree Preservation.
Source: Center for Watershed Protection

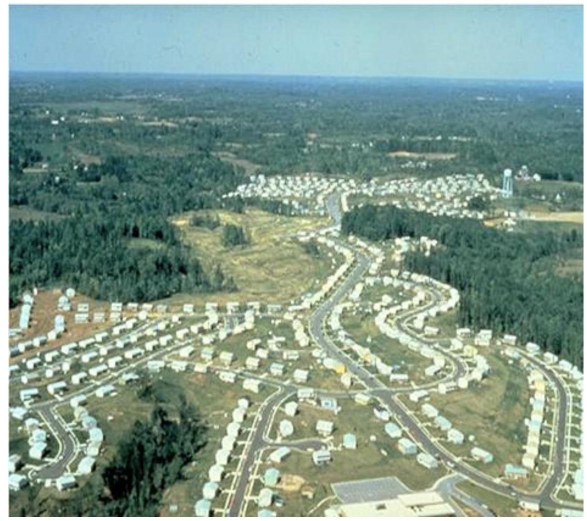


Figure 6.16. Subdivision Cleared and Grubbed from Property Line to Property Line
Source: Center for Watershed Protection

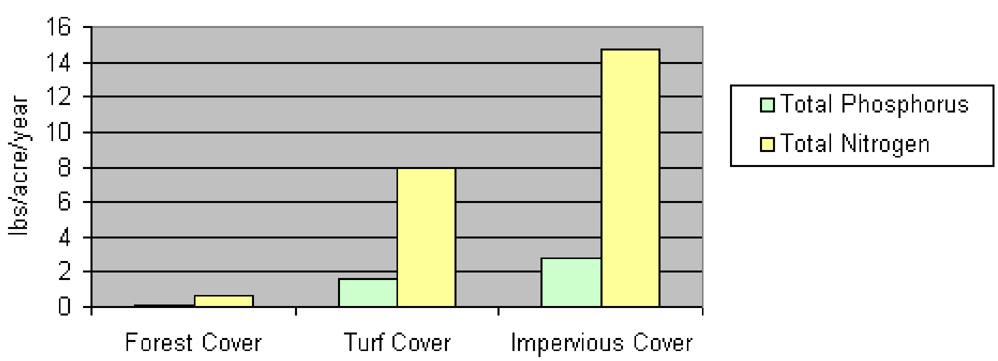


Figure 6.17. Comparison of Annual Nutrient Loads from Different Land Covers
Source: Chesapeake Bay Stormwater Training Partnership

Existing trees can be protected or new ones provided and used for applications such as landscaping, stormwater management practice areas, conservation areas, and erosion and sediment control. Where protection of existing trees and forest cover is desired, the developer should perform an inventory of existing trees and forest cover on the site as part of the site evaluation. Care should be taken to identify and preserve the highest quality forest stands prior to development. Specific mature tree/native vegetation targets can be established at the pre-development stage, based on reference sites and historic records. A professional arborist or forester can provide reliable advice regarding the health of trees and recommendations about what trees to preserve. Priority should be given to protecting or establishing hydrologically-connected tree clusters. In particular, trees within locally designated Resource Protection Areas

(RPAs) in localities subject to the Chesapeake Bay Preservation Act or elsewhere adjacent to streams are prime candidates for preservation (see the preceding Practice #2, *Preserving Riparian Buffers*).

As discussed in **Appendix 6-D** of this chapter, there are many environmental and economic reasons to establish trees instead of extensive lawn areas that require more intensive management, especially in open space to be conserved on the site. Having less lawn would result in less application of chemical fertilizers, pesticides and irrigation water, which are needed to maintain the desired health and appearance of turfgrass and which represent significant routine expenditures. Native species are generally preferable, requiring less attention and maintenance over time because their characteristics are attuned to the climatic zone of the site. The following are additional examples of the economic benefits of conserving or restoring tree and forest cover through the development process:

- A 1993 survey of members of the National Association of Homebuilders indicated that over 69 percent of the respondents described themselves as increasing the number of trees on their properties and were either thinking of or committed to continuing the practice (Andreason and Tyson, 1993).
- Two regional economic surveys documented that conserving forests on residential and commercial sites enhanced property values by an average of 6-15 percent and increased the rate at which units were sold or leased (Morales, 1980, and Weyerhauser, 1989).
- It has been conservatively estimated that over $1.5 billion per year is generated in tax revenue for communities in the U.S. due to the value of privately-owned trees on residential property (USDA, as cited by the National Arbor Day Foundation, 1996).
- Single family homes in Athens, Georgia, with an average of five trees in the front yard, sold for 3.5-4.5 percent more than houses without trees (National Arbor Day Foundation, 1996).
- A study of 14 variables that might influence the price of suburban homes in Manchester, Connecticut and Greece, New York found that trees ranked sixth in influencing the selling price. Trees on the property increased sale prices by 5-15 percent (National Arbor Day Foundation, 1996).
- Another study found that large old street trees (**Figure 6.18** below) were the most important indicator of community attractiveness (Coder, 1996). This community attractiveness is important due to its positive impact on property value. This same study stated that a $242 savings per home per year in cooling costs could be achieved when trees are present.
- In Austin, Texas, tree canopy was estimated to reduce stormwater flows by up to 28%, saving the city $122 million (MacDonald, 1996).
- In Atlanta, Georgia, officials estimate that the significant loss of trees and other vegetation over 25 years had resulted in a 6-9 degree elevation in temperature, increasing energy consumption for cooling, and a 4.4 billion cubic foot increase in stormwater runoff; officials estimated that at least $2 billion would be required to build containment facilities capable of storing the excess stormwater runoff (MacDonald, 1996, and American Forests, as cited in U.S. Water News, 1997)
- The Center for Watershed Protection has estimates of the long-term costs of maintaining different kinds of open-spaces in the urban landscape (**Table 6.8** below), showing that maintaining natural open space areas is by far the least expensive type of open space.

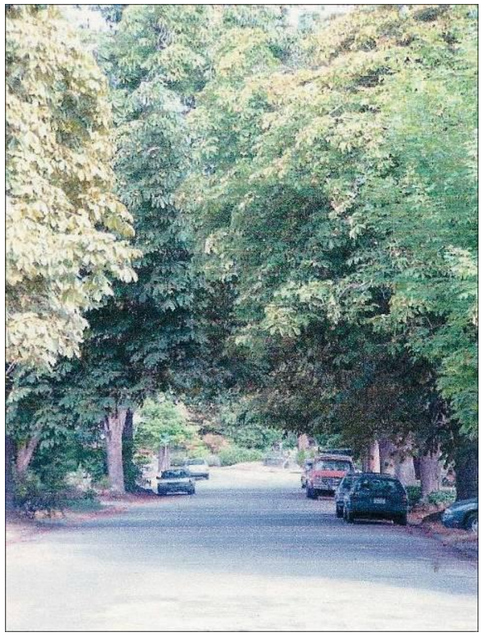


Figure 6-18. Street Trees in Seattle
Source: Puget Sound LID Technical Manual

Table 6.8. The Comparative Costs of Open Space Maintenance

Open Space Mgmt Strategy	Annual Maintenance Cost
Natural Open Space (only maintenance is trash/debris cleanup	$75/acre
Lawns (regular mowing)	$240 - $270/acre
Passive Recreation (trails, bike paths, etc.)	$200/acre

Source: CWP

Trees are ideal for all projects (see **Figure 6.19** below), including those where space is limited, in which trees can be placed along street frontages and in common space. Urban areas with higher numbers of trees exhibit hydrology more similar to natural conditions compared to urban areas without a tree canopy. Trees intercept storm water and retain a significant volume of the captured water on their leaves and branches, allowing for evaporation and providing runoff reduction benefits. For example, a large oak tree can intercept and retain more than 500 to 1,000 gallons of rainfall in a given year (Capiella, 2005). Since forest cover results in a lower runoff coefficient, areas of the development site under forest cover actually receive credit for runoff reduction in the Virginia Runoff Reduction Method Spreadsheet calculations. This is an additional incentive to conserve and restore forest cover on sites, since less total runoff means lower costs to manage the runoff.

Figure 6.19. Potential Tree Planting Areas at a Development Site
Source: MPCA (2006)

While the most effective interceptor trees are large canopied evergreen trees, deciduous trees can also provide a benefit. For example, a leafless Bradford Pear will retain more than one-half the amount of precipitation intercepted by an evergreen cork oak (Xiao et al., 2000b). The shade provided by trees keeps the ground under the trees cooler, thereby reducing the amount of heat gained in runoff that flows over the surface under the trees. This attenuation of heat in stormwater helps control increases in local stream temperatures. The presence of strategically located tree canopies also typically results in lower heating and cooling costs for adjacent buildings. Furthermore, on slopes, tree roots hold soil in place and prevent erosion.

The length of the slope of land draining toward tree cover should not exceed 150 feet from pervious areas and 75 feet from impervious areas. The gradient of land draining toward tree cover should not exceed 6 to 8 percent, depending upon the type of ground cover, unless a level spreader is used to convert runoff to sheet flow prior to entering the forested area (see Virginia Stormwater Design Specification No. 2, "Sheet Flow to a Vegetated Filter Strip or Conserved Open Space" – http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html). Ideally, forested areas should have multiple layers of vegetation, including herbaceous vegetation on the ground surface and a layer of native shrubs as understory vegetation (**Figure 6.20** below).

When establishing or enhancing riparian buffers on a development site, it is important to manage the buffer in a way that reduces the risk of catastrophic wildfire. Designing defensible space around structures protects property from wildfire damage. Design that takes into consideration reduction and management of fuels on the site reduces risks to local ecosystems, property and lives. A Fire Hazard Rating System and National Wildland/Urban Interface Fire Protection Program has been established, which provides recommendations for target vegetation around structures. More specific guidance about this can be found in **Tables 6.6 and 6.7** in **Section 6.5.1.2** (the previous practice – #2, *Preserve Riparian Buffers*).

Figure 6.20. Preserve or Establish Multiple Layers of Vegetation
Source: Day and Crafton (1978)

It is important to note that existing trees that are being preserved on the development site must be protected from the impacts of the construction process. Protective measures may include the use of signs, geotextile web fencing, or visible flagging (**Figure 6.21** below).The critical root zone(s) (CRZ) must be delineated (**Figure 6.22**) and protective barriers erected to prevent equipment from moving over and compacting the soils over the CRZs (**Figure 6.23**). Furthermore, construction materials should not be stored over CRZs, because the weight of the stored materials can also result in compacted soils (see **Figure 6.24** below).

Figure 6.21. Tree Protection Sign
Source: Adapted from State of Maryland

Figure 6.22. Compacted Soil
Source: Center for Watershed Protection

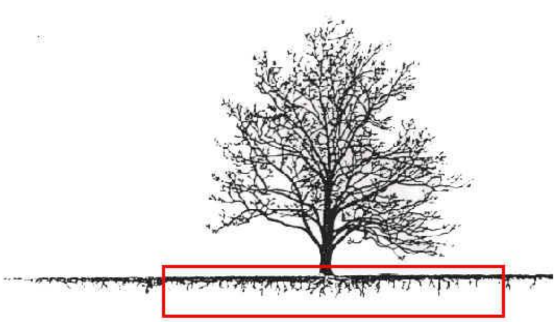


Figure 6.23. Most of a Tree's Roots Exist in the Top 1-Foot of Soil Depth and Extend Well Beyond the Canopy Drip Line
Source: City of Broomfield, Colorado

Figure 6.24. Construction Materials Stored Within Critical Root Zones of Trees Being Preserved
Source: Center for Watershed Protection

Site reforestation involves planting trees on existing turf or barren ground at a development site with the goal of establishing a mature tree canopy that can intercept rainfall, maximize infiltration and increase evapotranspiration. Trees can also be planted in stormwater management practices (e.g., bioretention areas, constructed wetlands, etc.) and in sidewalk planting pits. Whatever the target area, once the sites are selected, they should be evaluated for soil quality and other pertinent features, and the planting sites should be improved as needed (e.g., soil amendments). Tree planting sites and tree species should be chosen to fit the purpose of the development project and to withstand the constraints of an urban setting (see **Figure 6.25** below). Typically, inexpensive saplings are planted, coupled with quick establishment of an appropriate native ground cover around the trees so as to stabilize the soil and prevent influx of invasive plants. Turfgrass should be kept at least 24 inches from tree trunks.

Figure 6.25. (a – upper left): residential trees; (b – upper right): street trees; (c – center left): trees at a commercial site; (d – center right): trees at a parking lot; (e – lower left): parking lot trees at a commercial office building; (f – lower right): trees, bioretention, and conserved open space around and within a parking lot. Source: Sacramento (2007)

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.2: Use appropriate, non-invasive plants	0 (Prerequisite)
4.7: Use native plants	1 - 4
4.13: Reduce the risk of catastrophic wildfire	3

6.5.1.4. Environmental Site Design Practice #4: Avoid Floodplains

KEY BENEFITS	USING THIS PRACTICE
• Preserving floodplains provides a natural right-of-way and temporary storage for large floods Keeps people and structures out of harm's way • Helps to preserve riparian ecosystems and habitats • Can be combined with riparian buffer protection to create linear greenways	• Obtain maps of the 100-year floodplain from the local review authority • Ensure that all development activities do not encroach on the designated floodplain areas

Floodplains are the low-lying flat lands that border streams and rivers. Floodplain areas should be avoided for homes and other structures to minimize risk to human life and property damage, and to allow the natural stream corridor to accommodate flood flows. When a stream reaches its capacity and overflows its channel after storm events, the floodplain provides for storage and conveyance of these excess flows. In their natural state they reduce flood velocities and peak flow rates by the passage of flows through dense vegetation.

Floodplains play an important role in reducing sedimentation and filtering runoff, recharging groundwater, and providing travel corridors and habitat for both aquatic and terrestrial life. They can also provide an urban oasis for human health, recreation and well-being. Development in floodplain areas can reduce the ability of the floodplain to convey stormwater, potentially causing safety problems or significant damage to the site in question, as well as to both upstream and downstream properties. Most communities regulate the use of floodplain areas to minimize the risk to human life as well as to avoid flood damage to structures and property.

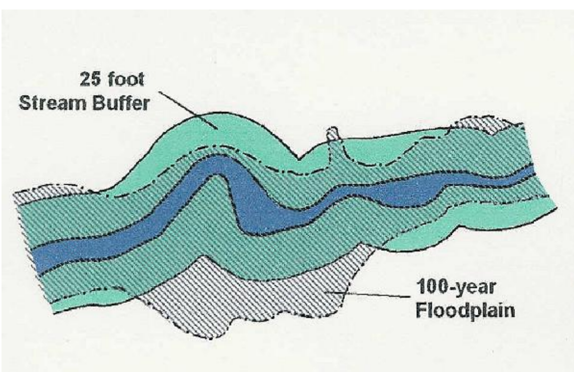


Figure 6.26. Floodplain Boundaries in Relation to a Riparian Buffer
Source: Georgia Stormwater Management Manual (2006)

Ideally, the entire 100-year full-buildout floodplain should be avoided for clearing or building activities, and should be preserved in a natural undisturbed state. Floodplain protection is complementary to riparian buffer preservation. Both of these ESD techniques preserve stream corridors in a natural state and allow for the protection of vegetation and habitat. Depending on the site topography, the boundaries of the100-year floodplain may lie inside or outside of a preserved riparian buffer corridor, as shown in **Figure 6.26**.

Maps of the 100-year floodplain can typically be obtained through the local review authority. Developers and builders should also ensure that their site design comply will any other relevant local floodplain and FEMA requirements.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
1.2: Protect floodplain functions	0 (Prerequisite)

6.5.1.5. Environmental Site Design Practice #5: Avoid Steep Slopes

KEY BENEFITS	USING THIS PRACTICE
• Preserving steep slopes helps to prevent soil erosion and degradation of stormwater runoff • Steep slopes can be kept in an undisturbed natural condition to help stabilize hillsides and soils • Building on flatter areas will reduce the need for cut-and-fill and grading	• Avoid development on steep slope areas, especially those with a grade of 15% or greater • Minimize grading and flattening of hills and ridges

Steep slopes should be avoided due to the potential for soil erosion and increased sediment loading. Excessive grading and flattening of hills and ridges should be minimized. Developing on steep slope areas has the potential to cause excessive soil erosion and stormwater runoff during and after construction. Past studies by the SCS (now NRCS) and others have shown that soil erosion is significantly increased on slopes of 15 percent or greater. In addition, the nature of steep slopes means that greater areas of soil and land area are disturbed to locate facilities on them compared to flatter slopes, as demonstrated in **Figure 6.27**.

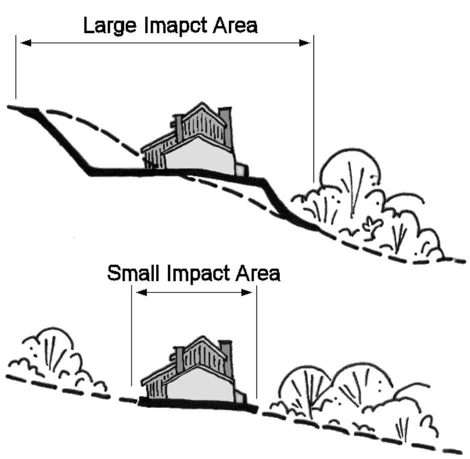


Figure 6.27. Flattening Steep Slopes for Building Sites Uses More Land Area Than Building on Flatter Slopes
Source: Georgia Stormwater Management Manual (2006)

Therefore, development on slopes with a grade of 15% or greater should be avoided if possible to limit soil loss, erosion, excessive stormwater runoff, and the degradation of surface water. Excessive grading should be avoided on all slopes, as should the flattening of hills and ridges. Steep slopes should be kept in an undisturbed natural condition to help stabilize hillsides and soils.

On slopes greater than 25%, no development, regrading, or stripping of vegetation should be considered unless the disturbance is for roadway crossings or utility construction and it can be demonstrated that the roadway or utility improvements are absolutely necessary in the sloped area.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.4: Minimize soil disturbance in design and construction	6

6.5.2. Using Low Impact Site Design Techniques

After a site analysis has been performed and conservation areas have been delineated, there are numerous opportunities in the site design and layout phase to reduce both water quantity and quality impacts of stormwater runoff. These primarily deal with the location and configuration of impervious surfaces or structures on the site and include the following practices and techniques covered over the next several pages:

- Fit the Design to the Terrain
- Locate Development in Less Sensitive Areas
- Reduce Limits of Clearing and Grading
- Utilize Open Space Development
- Consider Creative Development Design

The goal of lower impact site design techniques is to lay out the elements of the development project in such a way that the site design (i.e. placement of buildings, parking, streets and driveways, lawns, undisturbed vegetation, buffers, etc.) is optimized for effective stormwater management. That is, the site design takes advantage of the site's natural features, including those placed in conservation areas, as well as any site constraints and opportunities (topography, soils, natural vegetation, floodplains, shallow bedrock, high water table, etc.) to prevent both on-site and downstream stormwater impacts. **Figure 6.28** shows a development that has utilized several lower impact site design techniques. **Figures 6.29 through 6.31** show other aspects of low-impact development. Stormwater management practices that contain runoff volume on-site for reuse or infiltration are emphasized.

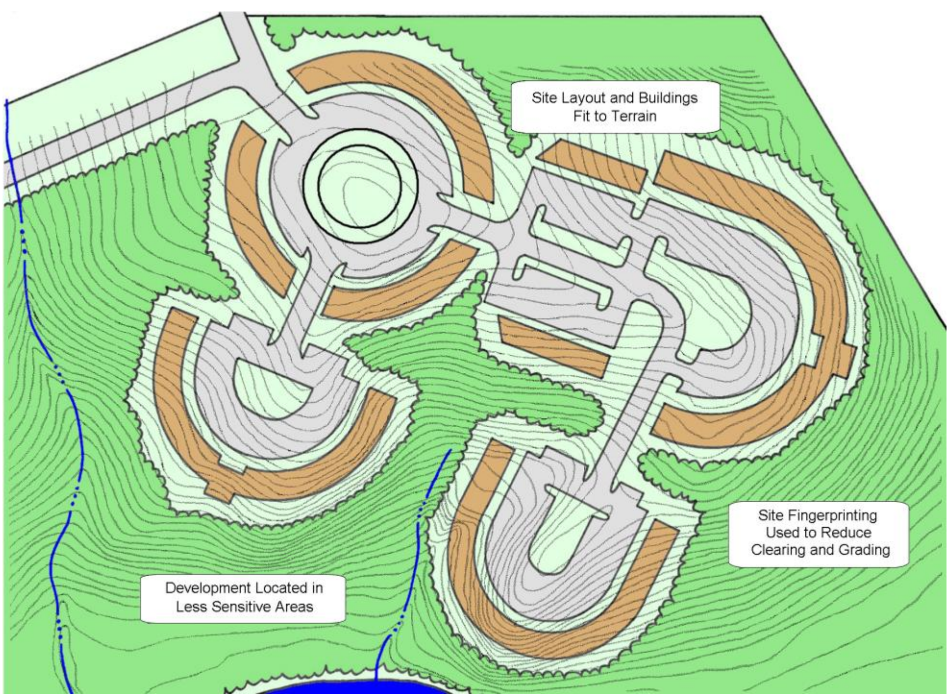


Figure 6.28. Development Design Using Several Lower Impact Site Design Techniques
Source: ARC (2006)

Figure 6.29. Composite Site Analysis of a Residential Lot
Source: Puget Sound LID Technical Manual (2005)

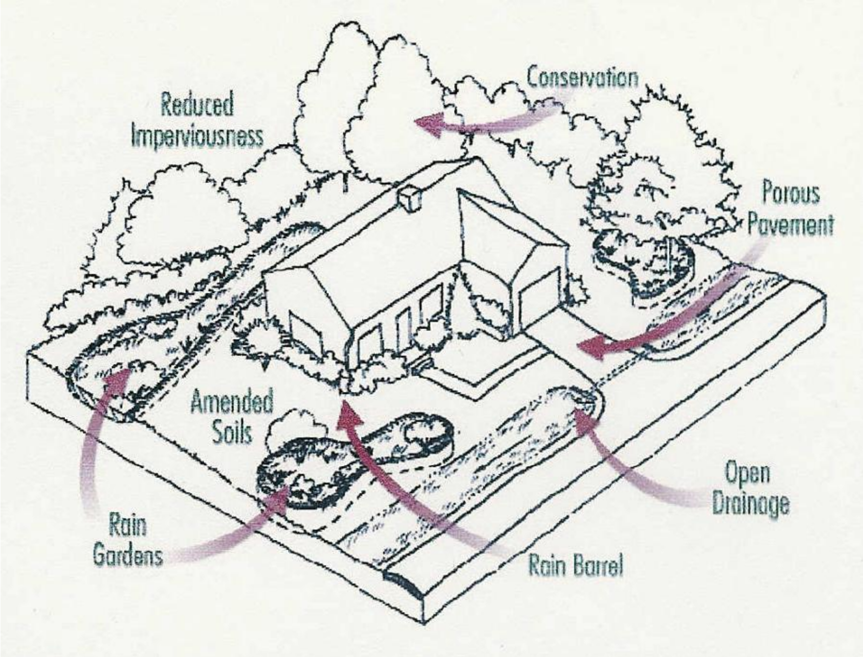


Figure 6.30. LID Practices Incorporated at a Residential Lot
Source: Puget Sound LID Technical Manual (2005)

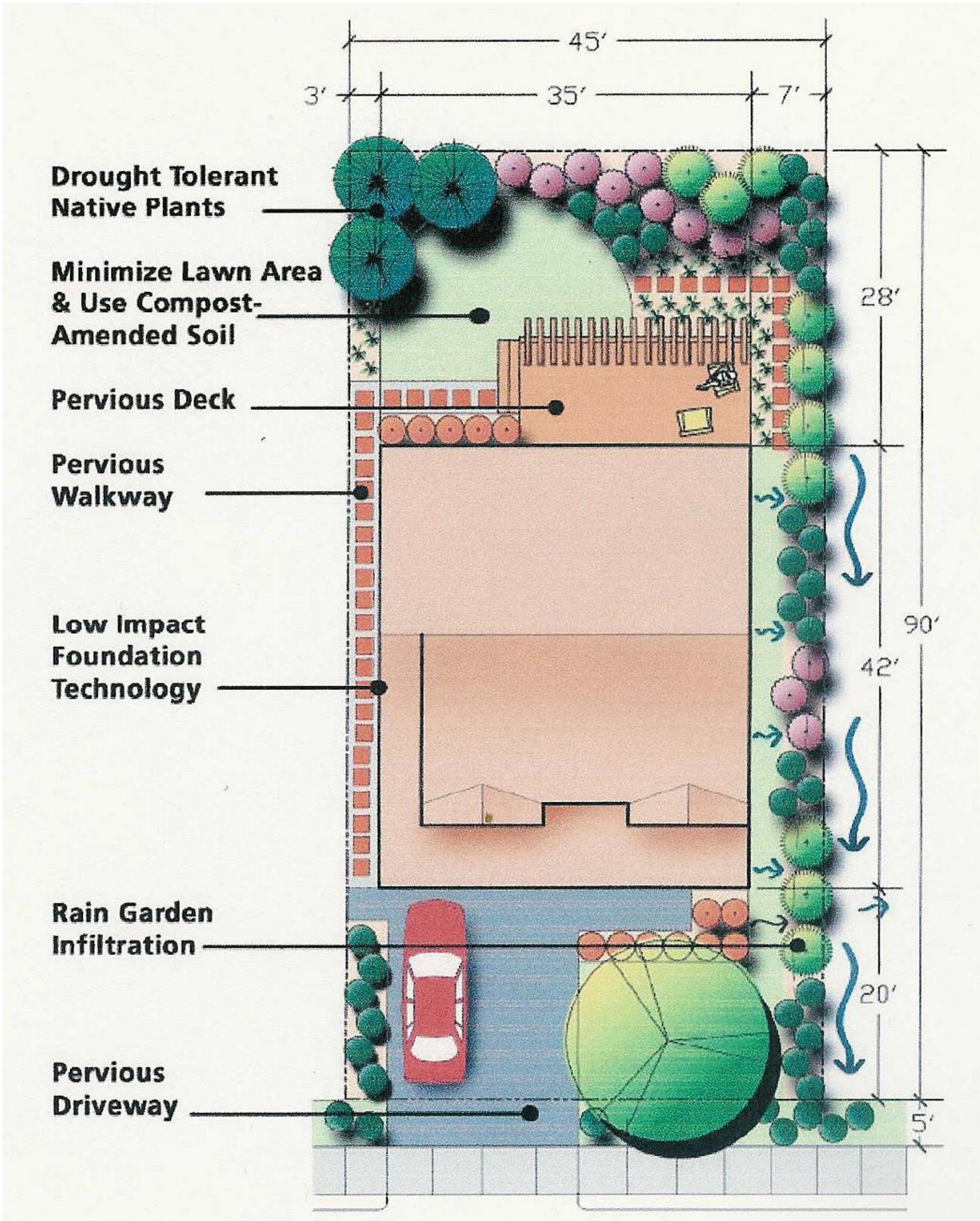


Figure 6.31. Use of LID Practices on a Medium- to High-Density Lot
Source: Puget Sound LID Technical Manual (2005)

6.5.2.1. Environmental Site Design Practice #6: Fit the Design to the Terrain

KEY BENEFITS	USING THIS PRACTICE
• Helps to preserve the natural hydrology and drainageways of a site • Reduces the need for grading and land disturbance • Provides a framework for site design and layout	• Develop roadway patterns to fit the site terrain. Locate buildings and impervious surfaces away from steep slopes, drainageways and floodplains

The layout of roadways and buildings on a site should generally conform to the landforms on a site. Natural drainageways and stream buffer areas should be preserved by designing road layouts around them. Buildings should be sited to utilize the natural grading and drainage system and avoid the unnecessary disturbance of vegetation and soils. All site layouts should be designed to conform with or "fit" the natural landforms and topography of a site. This helps to preserve the natural hydrology and drainageways on the site, as well as reduces the need for grading and disturbance of vegetation and soils. **Figure 6.32** illustrates the placement of roads and homes in a residential development.

Roadway patterns on a site should be chosen to provide access schemes which match the terrain. In rolling or hilly terrain, streets should be designed to follow natural contours to reduce clearing and grading. Street hierarchies with local streets branching from collectors in short loops and cul-de-sacs along ridgelines help to prevent the crossing of streams and drainageways as shown in **Figure 6.33** below. In flatter areas, a traditional grid pattern of streets or "fluid" grids which bend and may be interrupted by natural drainageways may be more appropriate (see **Figure 6.34** below). In either case, buildings and impervious surfaces should be kept off of steep slopes, away from natural drainageways, and out of floodplains and other lower lying areas. In addition, the major axis of buildings should be oriented parallel to existing contours.

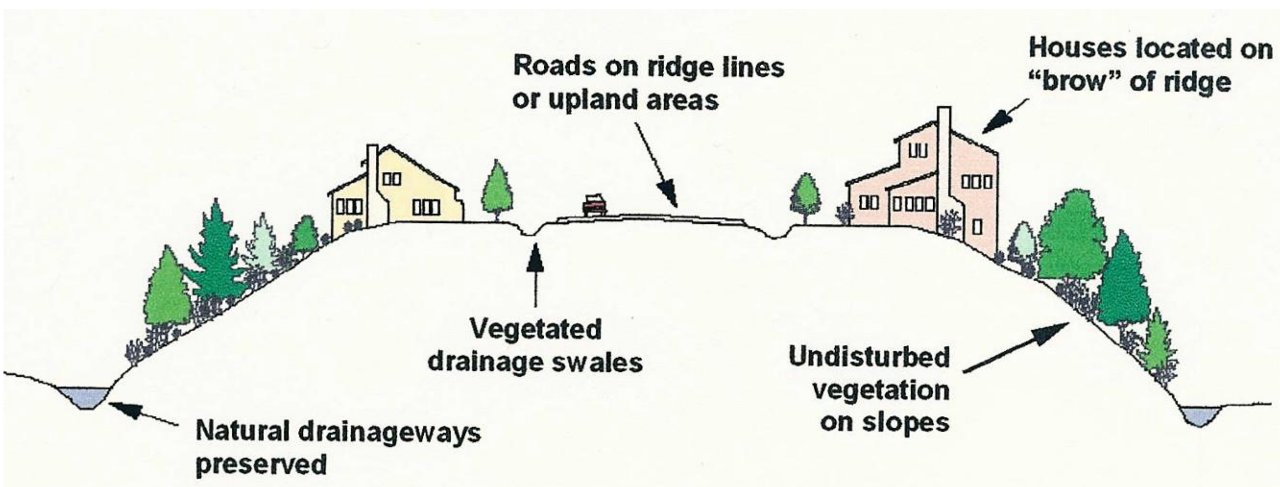


Figure 6.32. Preserving the Natural Topography of the Site
(Adapted from Sykes, 1989)

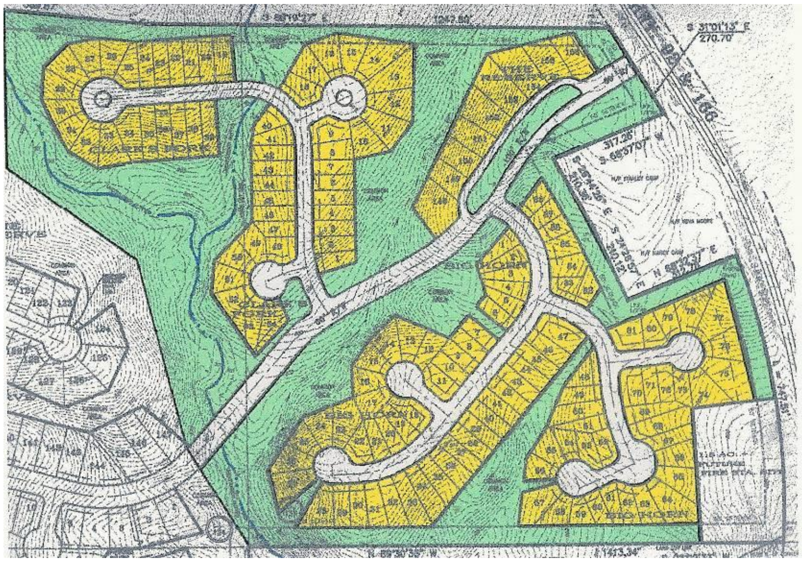


Figure 6.33. Subdivision Design for Hilly or Steep Terrain Uses Branching Streets from Collectors that Preserves Natural Drainageways and Stream Corridors
Source: ARC (2006)

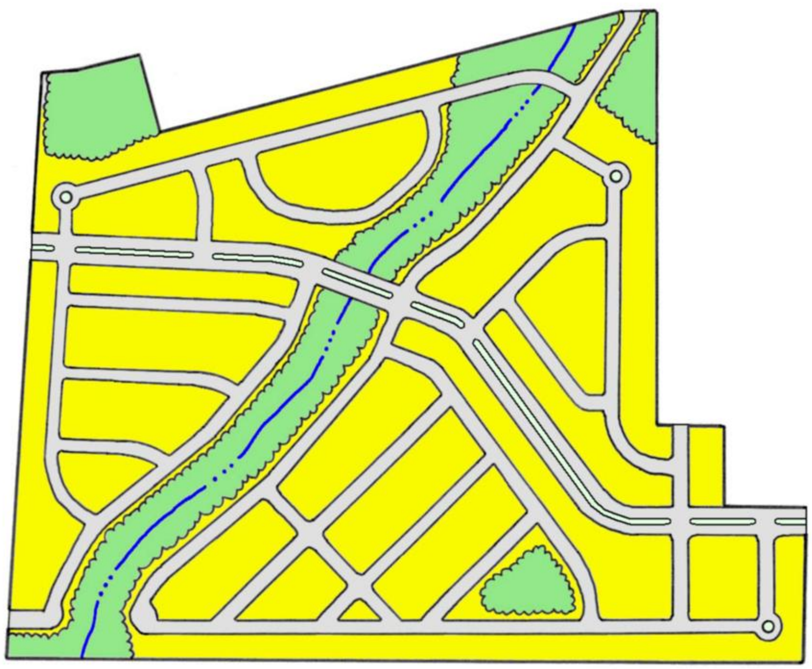


Figure 6.34. A Subdivision Design for Flat Terrain Uses a Fluid Grid Layout that is Interrupted by the Stream Corridor
Source: ARC (2006)

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.4: Minimize soil disturbance in design and construction	6

6.5.2.2. Environmental Site Design Practice #7: Locate Development in Less Sensitive Areas

KEY BENEFITS	USING THIS PRACTICE
• Areas with highly permeable soils can be used as nonstructural stormwater infiltration zones • Helps to preserve the natural hydrology and drainageways of a site • Makes most efficient use of natural site features for preventing and mitigating stormwater impacts • Provides a framework for site design and layout	• Use soil surveys to determine site soil types • Lay out the site design to minimize the hydrologic impact of structures and impervious surfaces • Leave areas of porous or highly erodible soils as undisturbed conservation areas

Healthy soils effectively cycle nutrients; store carbon as organic matter; minimize runoff and maximize water holding capacity; absorb excess nutrients, sediments and pollutants; provide a healthy rooting environment and habitat to a wide range of organisms; and maintain their structure and aggregation. Porous soils, such as sand and gravels, provide an opportunity for groundwater recharge of stormwater runoff and should be preserved as a potential stormwater management option. Preserving soil horizons saves money by reducing the need for soil restoration and surface drainage improvements. Unstable or easily erodible soils should be avoided due to their greater erosion potential. By limiting grading, sites can also reduce costs for construction machinery and transport of imported soils.

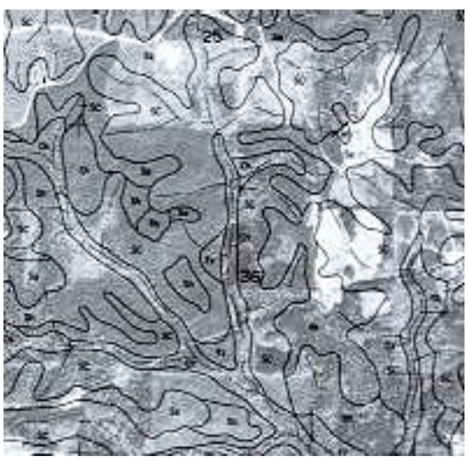


Figure 6.35. Soil Mapping Information Can Be Used To Guide Development
Source: USDA-NRCS

Soils on a development site should be mapped in order to preserve areas with porous soils, and to identify those areas with unstable or erodible soils as shown in the Soil Survey (see **Figure 6.35**). Soil surveys can provide a considerable amount of information relating to all relevant aspects of soils. General soil types should be delineated on concept site plans to guide site layout and the placement of buildings and impervious surfaces.

To minimize the hydrologic impacts on the existing site land cover, the area of development should be located in areas of the site that are less sensitive to disturbance or have a lower value in terms of hydrologic function and ecosystem services. In much the same way that a development should be designed to conform to terrain of the site, a site layout should also be designed so that the areas of development are placed in the locations of the site that minimize the hydrologic and ecologic impact of the project, using the following methods:

- Avoid developing on land designated as prime farmland, unique farmland, or farmland of statewide importance, in order to conserve the most productive farmland for use by future generations. Once converted to industrial and urban uses, this farmland is lost and cannot be regained.
- Given the choice, select sites on brownfields or greyfields for redevelopment and/or otherwise within existing communities where necessary infrastructure already exists.
- Locate buildings and impervious surfaces away from stream corridors, floodplains, wetlands and natural drainageways. Use buffers to preserve and protect riparian areas and corridors.
- Areas on a site with highly erodible or unstable soils should be avoided for land disturbing activities and buildings to prevent erosion and sedimentation problems as well as potential future structural problems. These areas should be left in an undisturbed and vegetated condition.
- Areas of the site with porous soils should left in an undisturbed condition, as much as is feasible, and/or used as stormwater runoff infiltration zones. Buildings and impervious surfaces should be located in areas with less permeable soils (**Figure 6.36**). These areas should ideally be incorporated into undisturbed natural or open space areas.

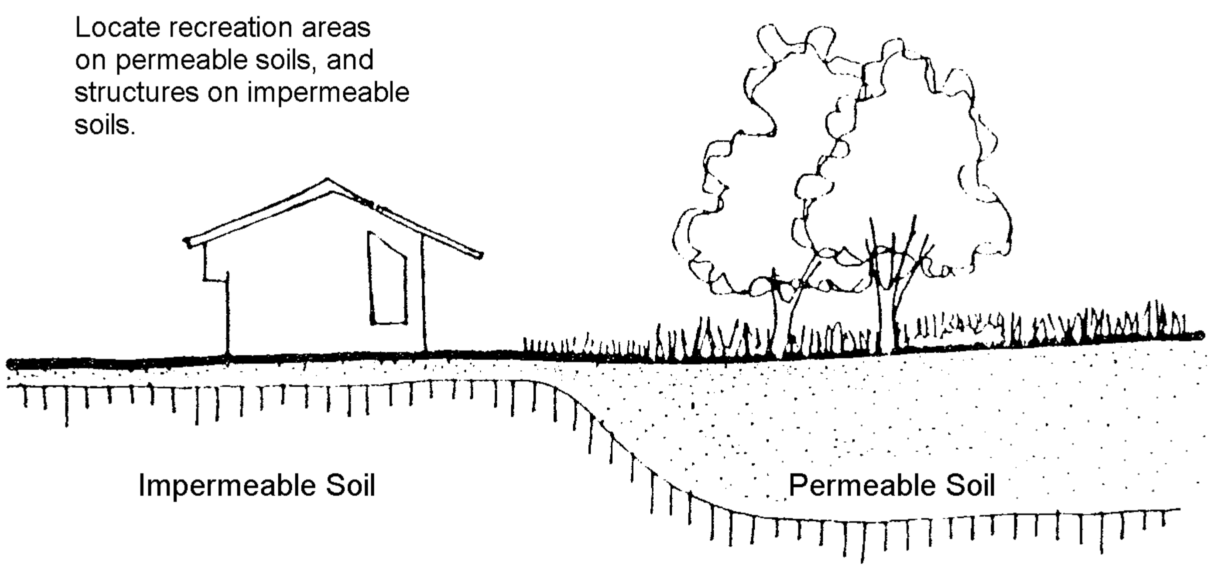


Figure 6.36. Avoid Building On or Disturbing Porous Soils
Source: Day and Crafton (1978)

Infiltration of stormwater into the soil reduces both the volume and peak discharge of runoff from a given rainfall event, and also provides for water quality treatment and groundwater recharge. Soils with maximum permeability (hydrologic soil group A and B soils such as sands and sandy loams) allow for the most infiltration of runoff into the subsoil.

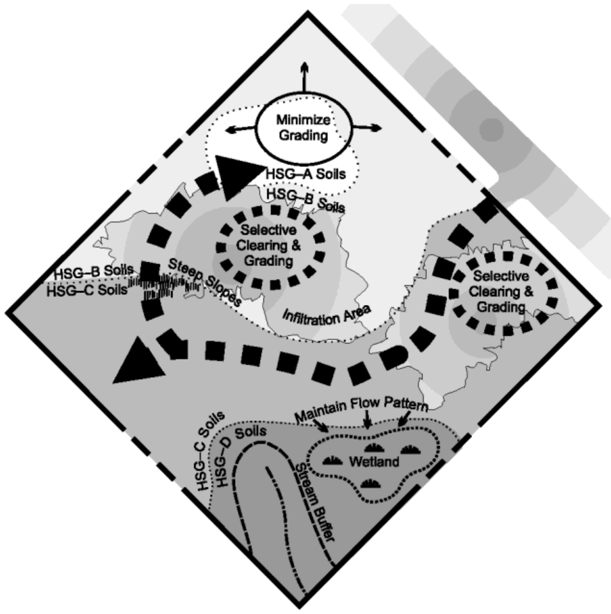


Figure 6.37. Guiding Development to Less Sensitive Areas of a Site
Source: Georgia Stormwater Management Manual (2001)

Avoid land disturbing activities or construction on areas with steep slopes or unstable soils.

- Minimize the clearing of areas with dense tree canopy or thick vegetation, and ideally preserve them as natural conservation areas
- Ensure that natural drainageways and flow paths are preserved, where possible. Avoid the filling or grading of natural depressions and ponding areas.
- Design carefully around floodplains. Access to buildings and residences should be from the landward direction. Stream crossings should be as nearly perpendicular as possible (see **Figure 6.38** below).

Figure 6.37 above shows a development site where the natural features have been mapped in order to delineate the hydrologically sensitive areas. Through careful site planning, sensitive areas can be set aside as natural open space areas (see Environmental Site Design Practice #9). In many cases, such areas can be used as buffer spaces between land uses on the site or between adjacent sites.

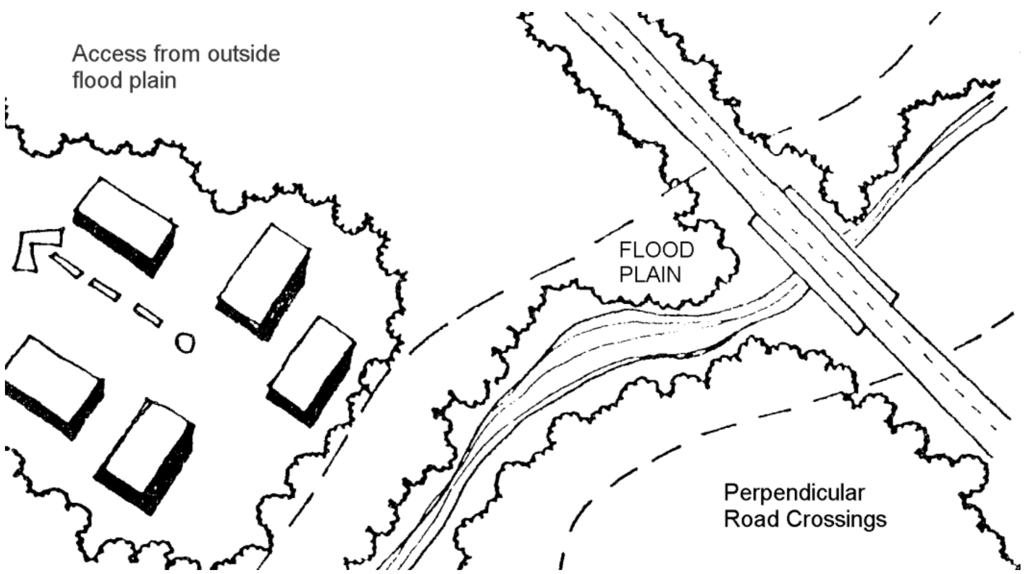


Figure 6.38. Design Carefully Around Floodplains
Source: Day and Crafton (1978)

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
1.1: Limit development of soils designated as prime farmland, unique farmland, and farmland of statewide importance	0 (Prerequisite)
1.2: Protect floodplain functions	0 (Prerequisite)
1.3: Preserve wetlands	0 (Prerequisite)
1.4: Preserve threatened and endangered species	0 (Prerequisite)
1.5: Select brownfields or greyfields for redevelopment	5 - 10
1.6: Select sites within existing communities	6

6.5.2.3. Environmental Site Design Practice #8: Reduce the Limits of Clearing and Grading

KEY BENEFITS	USING THIS PRACTICE
• Preserves more undisturbed natural areas on a development site • Techniques can be used to help protect natural conservation areas and other site features	• Establish limits of disturbance for all development activities • Use site footprinting to minimize clearing and land disturbance

Clearing and grading of the site should be limited to the minimum amount needed for the development function, road access, and the necessary infrastructure (e.g., utilities, wastewater disposal, and stormwater management). Minimal disturbance methods should be used to limit the amount of clearing and grading that takes place on a development site, preserving more of the undisturbed vegetation, good soils, and natural hydrology of a site. Unnecessarily removing forest cover will decrease infiltration and, thus, increase runoff and the possibility of erosion and siltation (**Figure 6.39**). Vegetation plays an enormous role in regulating stream flow and maintaining water quality. Areas which contain high-quality, stable, or unique vegetation should be identified and preserved.

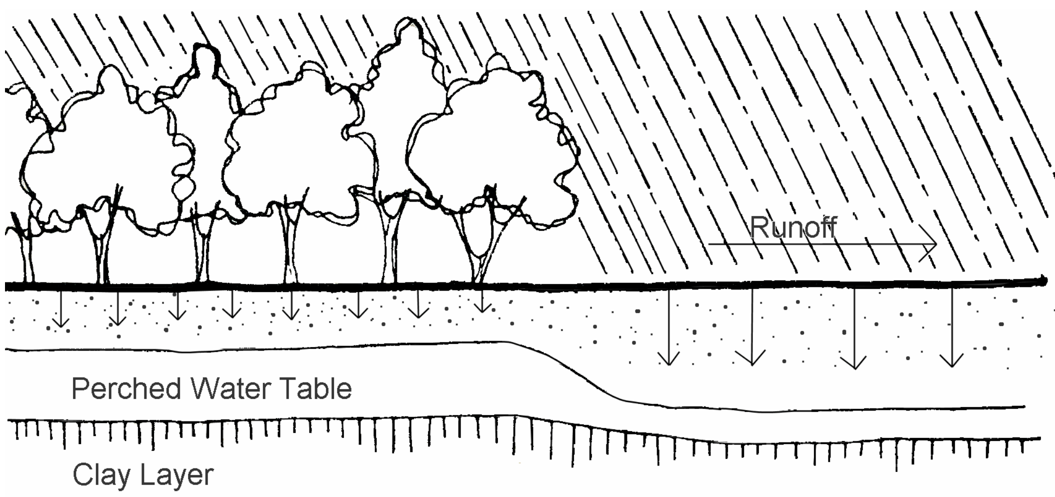


Figure 6.39.Clearing Vegetation Decreases Infiltration and Baseflow and Increases Runoff
Source: Day and Crafton (1978)

Appropriate methods include the following:

- Avoiding mass grading and establishing physically marked limits of disturbance (LOD) based on maximum disturbance zone radii/lengths. These maximum distances should reflect reasonable construction techniques and equipment needs together with the physical situation of the development site such as slopes or soils. LOD distances may vary by type of development, size of lot or site, and by the specific development feature involved.
- Using site "footprinting" which maps all of the limits of disturbance to identify the smallest possible land area on a site which requires clearing or land disturbance for building

footprints, construction access, and safety setbacks. Examples of site footprinting are illustrated in **Figures 6.40 and 6.41**.

- Fitting the site design to the terrain.
- Use alternative site designs that incorporate open-space or "cluster" developments.
- Using special procedures and equipment which reduce land disturbance.

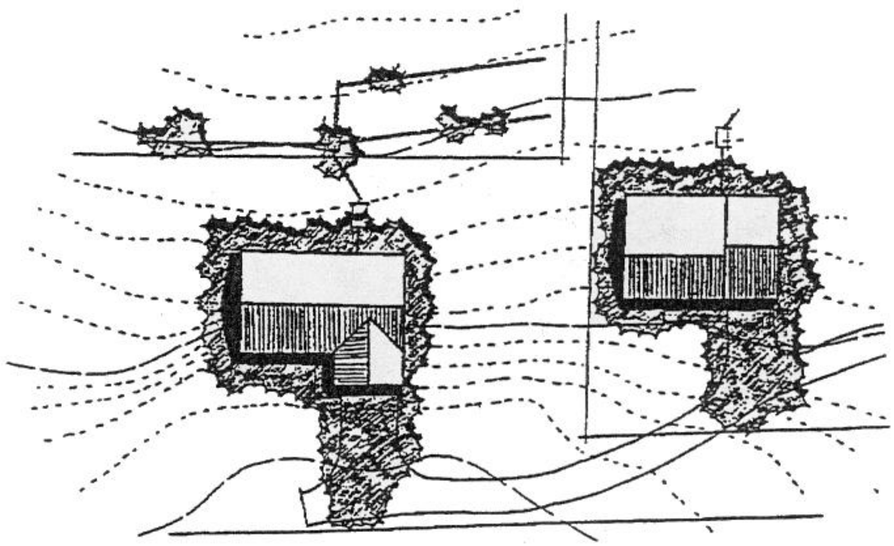


Figure 6.40. Establishing Limits of Clearing
Source: DDNREC (1997)

Figure 6.41. Example of Site Footprinting
Source: ARC (2006)

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.4: Minimize soil disturbance in design and construction	6
4.5: Preserve all vegetation designated as special status	5
4.6: Preserve or restore appropriate plant biomass on the site	3 - 8
4.8: Preserve plant communities native to the ecoregion	2 - 6

6.5.2.4. Environmental Site Design Practice #9: Use Open Space Development

KEY BENEFITS	USING THIS PRACTICE
• Can be used to help protect natural conservation areas and other site features • Can be used to preserve natural hydrology and drainageways and improve watershed protection • Reduces the need for grading and land disturbance • Reduces infrastructure needs and development costs • Increases community recreational space	• Use a site design which concentrates development and preserves open space and natural areas of the site
This practice reflects the CWP Better Site Design Principles #11 (Open Space Design), #15 (Open Space Management), and #21 (Conservation Incentives)	

Open space site designs (sometimes referred to as conservation development or cluster development) incorporate smaller lot sizes to reduce overall impervious cover while providing protection for open space and natural areas opportunities for on-site stormwater runoff reduction and treatment, and protection of local water resources. Open space development is typically applied to residential development. Where open space design is available as an option under local zoning codes, the localities typically relax minimum lot sizes, setbacks and frontage distances in order to maintain the same number of dwelling units at the site while achieving the conservation purposes.

The Department encourages localities to consider making open space development a by-right form of development, so that zoning variances or special use permits are unnecessary, and to provide incentives for developers to make greater use of this form of development. Incentives and flexibility in the form of density compensation, buffer averaging, and property tax reduction, among others, should be encouraged to promote conservation of stream buffers, forests, meadows, and other areas of environmental value. In addition, compensatory mitigation consistent with locally adopted watershed plans should be encouraged. More detailed guidance regarding such options can be found in the discussion of the Center for Watershed Protection’s Better Site Design Principle No. 21 (in CWP 1998a).

The ability to implement open space designs depends to a great extent on the base zoning density of the open space design. Flexibility sharply declines as the density of the base zone increases. Generally, high density residential zones (more than six dwelling units per acre) are not feasible for open space developments, simply due to the lack of space.

Open space developments have many benefits compared with conventional commercial developments or residential subdivisions: they can reduce impervious cover, stormwater pollution, construction costs, and the need for grading and landscaping, while providing for the conservation of good soils, high quality, stable or unique vegetation, wildlife habitat, and community open space. **Figure 6.42** and **Figure 6.43** below show examples of open space developments.

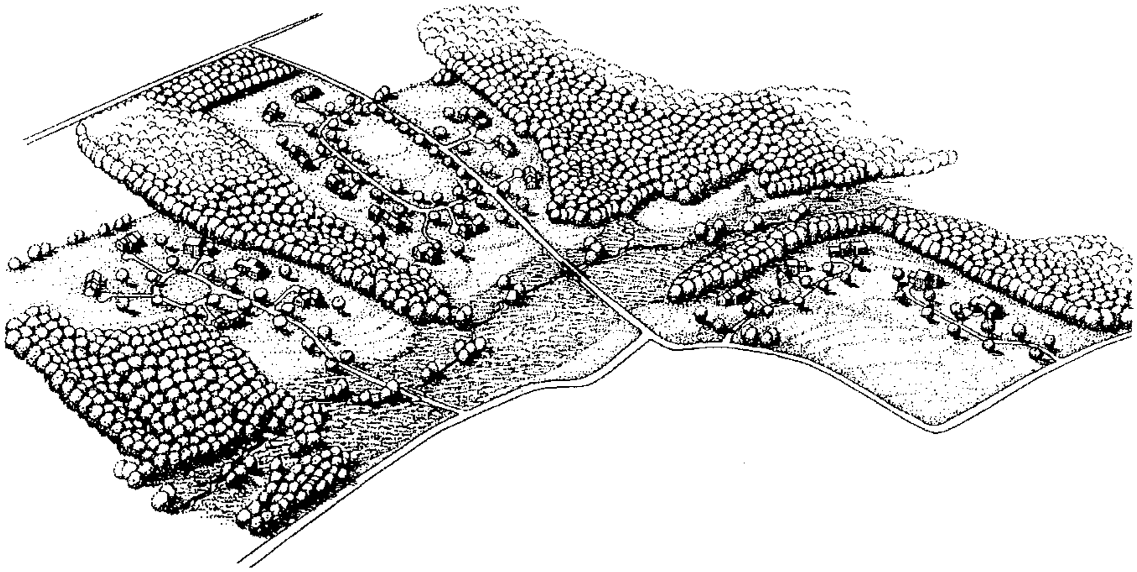


Figure 6.42. Open Space Subdivision Site Design Example
Source: DE DNREC (1997)

Figure 6.43. Aerial View of an Open Space Subdivision
Source: Chesapeake Bay Stormwater Training Partnership

Along with reduced imperviousness, open space designs provide a host of other environmental benefits lacking in most conventional designs. These developments reduce potential pressure to encroach on conservation and buffer areas because enough open space is usually reserved to accommodate these protection areas. As less land is cleared during the construction process, alteration of the natural hydrology and the potential for soil erosion are also greatly diminished. Perhaps most importantly, open space design typically results in 25 to 50 percent of the development site being placed in conservation areas that would not otherwise be protected.

Some measure of the value of open space design in reducing impervious cover can be gleaned from a series of "redesign" analyses (see **Table 6.9**). In each case, an existing conventional residential subdivision was "redesigned" using open space design principles. The resulting change in impervious cover was measured from the two plans. These studies suggest that open space designs can reduce impervious cover by 40-60 percent and stormwater runoff volume by 20-60+ percent, when compared to conventional subdivision designs, particularly if narrow streets can also be used at the site. The value of open space designs in reducing impervious cover is evident over most residential zones, although only minor reductions in impervious cover occur in areas which used very small lot size (1/8 acre lots and smaller) in the original zoning.

Table 6.9. Redesign Analyses Comparing Impervious Cover and Stormwater Runoff from Conventional and Open Space Subdivisions

Residential Subdivision Name	Conventional Zoning for the Subdivision	Impervious Cover at the Site			% Reduction in Stormwater Runoff (%)
		Conventional Design (%)	Open Space Design (%)	Net Change (%)	
Remlick Hall [1]	5 acre lots	5.4	3.7	-31	20
Duck Crossing [2]	3-4 acre lots	8.3	5.4	-35	23
Tharpe Knoll [3]	1 acre lots	13	7	-46	44
Chapel Run [3]	1/2 acre lots	29	17	-41	31
Pleasant Hill [3]	1/2 acre lots	26	11	-58	54
Prarie Crossing [4]	1/2 to 1/3 acre lots	20	18	-20	66
Rappahannock [2]	1/3 acre lots	27	20	-24	25
Buckingham Greene [3]	1/8 acre lots	23	21	-7	8
Belle-Hall [5]	High Density	35	20	-43	31
Sources: [1] Maurer, 1996; [2] CWP, 1998b; [3] DE DNREC, 1997; [4] Dreher, 1994; and [5] SCCCL, 1995.					

Source: CWP, 1998a

Decreased stormwater runoff translates to less stormwater pollution. Again, several redesign analyses have compared the stormwater pollution loads of conventional and open space developments using simple models (see **Table 6.10** below). Significant reductions in stormwater pollutant loadings generally occur when open space designs are used – comparable to what can be achieved if stormwater best management practices were installed at the conventional site.

Open space developments can also be significantly less expensive to build than conventional projects. Most of the cost savings are due to reduced infrastructure cost for roads and stormwater management controls and conveyances. The examples in **Table 6.11** below demonstrate infrastructure cost savings ranging from 11-66 percent.

Table 6.10. Redesign Analyses Comparing Stormwater Pollution Loads from Conventional and Open Space Subdivisions

Residential Subdivision	Change in Phosphorus Load (%)	Change in Nitrogen Load (%)	Other
Remlick Hall [1]	-42	-42	
Prarie Crossing [2]	-81	N/A	92% TSS reduction
Rappahannock [3]	-60	-45	
Belle-Hall [4]	-67	-69	
Sources: [1] Maurer, 1996; [2] Dreher, 1994; [3] CWP, 1998b; and [4] SCCCL, 1995			

Source: CWP, 1998a

Table 6.11. Projected Construct Cost Savings for Open Space Designs from Redesign Analyses

Residential Development	Construction Cost Savings (%)	Notes
Remlick Hall [1]	52	Includes costs for engineering, road construction, and obtaining water and sewer permits
Duck Crossing [2]	12	Includes roads, stormwater management, and reforestation
Tharpe Knoll [3]	56	Includes roads and stormwater management
Chapel Run [3]	64	Includes roads, stormwater management, and reforestation
Pleasant Hill [3]	43	Includes roads, stormwater management, and reforestation
Rappahannock [2]	20	Includes roads, stormwater management, and reforestation
Buckingham Greene [3]	63	Includes roads and stormwater management
Canton, Ohio [4]	66	Includes roads and stormwater management
Sources: [1] Maurer, 1996; [2] Dreher, 1994; [3] CWP, 1998b; and [4] NAHB, 1986		

Source: CWP, 1998a

While open space developments are frequently less expensive to build, developers find that these properties often command higher prices than those in more conventional developments. Several studies estimate that residential properties in open space developments garner premiums that are higher than conventional subdivisions and moreover, sell or lease at an increased rate (Zielinski, 2001). Open space development also reduces the heat island effect of urban areas, and the preserved vegetation can help to reduce heating and cooling costs, providing long-term economies. Many studies have shown that a well-designed and marketed open space development can be very desirable to home buyers. Some examples are presented in **Table 6.12** below.

Once established, common open space and natural conservation areas must be managed by a responsible party able to maintain the areas in a natural state in perpetuity. Typically, the conservation areas are protected by legally enforceable deed restrictions, conservation easements, and maintenance agreements.

A 1992 survey of local open space design regulations conducted by Heraty revealed that the open space requirements were poorly defined in most communities. For example, less than a third of local cluster ordinances required that open space be consolidated. Only 10 percent required that a specified portion of the open space be maintained and managed in a natural state. Similarly, few communities clearly specify allowable uses for open space areas. Instead, most communities rely on community associations to manage open space and determine allowable uses.

Table 6.12. Examples of Successful Open Space Developments

Subdivision Name	Location	Percent Open Space	Notes
Farmview	Bucks County, PA	*	The fastest selling subdivision in its price range, with lots from 1/2 to 1/3 the size of competing projects (Arendt, et al., 1994)
Palmer Ranch	Sarasota, FL	36	93% of existing wetlands at the site were preserved. Accounted for 30% of the new home market in Sarasota in 1994 (Ewing, 1996).
Fields of St. Croix	Lake Elmo, MN	60	80% of home sites in the first phase were sold within 6 months (NAHB, 1997)
Westgreen	Leesburg, VA	39	Targeted to young professionals and empty-nesters. Every lot in Phase I sold during the first weekend (ULI, 1992)
* More than 23% was preserved as open space and 31% was preserved as productive farm land.			

Source: CWP, 1998a

Realistically, few community associations have the legal or financial resources to adequately manage open space, particularly if it is intended for active recreation. Furthermore, it is difficult for individual community associations to manage interconnected open spaces in a cohesive manner. The concern that homeowners lack the money, organization or technical ability to adequately maintain common areas is often cited as the reason for communities to prohibit or restrict open space designs.

However, open space managed in natural condition actually has minimal annual maintenance cost. This is one reason why communities should encourage designers to retain as much open space as possible in a natural condition. Communities should also explore more reliable methods to assure that the responsibility for open space management can be met within a development. The two primary options are to (1) create a community organization or (2) to shift the responsibility to a third party, such as a land trust or park, by means of a conservation easement. The latter technique is especially useful in developments that have high quality conservation areas retained in open space.

Communities that have cluster or open space ordinances should revisit them to ensure that open space is well planned and, where possible, connected. Clear performance criteria for open space consolidation, maintenance in natural condition, allowable uses, and future management should be carefully considered. More detailed guidance about managing open space can be found in the discussion of Principle No. 15 in CWP 1998a.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.5: Preserve all vegetation designated as special status	5
4.6: Preserve or restore appropriate plant biomass on the site	3 - 8
4.12: Reduce urban heat island effects	3 - 5

6.5.2.5. Environmental Site Design Practice #10: Consider Creative Development Design

KEY BENEFITS	USING THIS PRACTICE
• Allows flexibility to developers to implement creative site designs which include environmental site design practices • May be useful for implementing an open space development	• Check with your local review authority to determine if the community supports Planned Unit Developments (PUDs) • Determine the type and nature of deviations allowed and other criteria for receiving PUD approval

Planned Unit Developments (PUDs) allow a developer or site designer the flexibility to design a residential, commercial, industrial, or mixed-use development in a fashion that best promotes effective stormwater management and the protection of environmentally sensitive areas. A Planned Unit Development (PUD) is a type of planning approval available in some communities which provides greater design flexibility by allowing deviations from the typical development standards required by the local zoning code with additional variances or zoning hearings. The intent is to encourage better designed projects through the relaxation of some development requirements, in exchange for providing greater benefits to the community. PUDs can be used to implement many of the other stormwater-related ESD practices covered in this Handbook and to create site designs that maximize natural nonstructural approaches to stormwater management. Examples of the types of zoning deviations which are often allowed through a PUD process include:

- Allowing uses not listed as permitted, conditional or accessory by the zoning district in which the property is located
- Modifying lot size and width requirements
- Reducing building setbacks and frontages from property lines (e.g., zero lot line configurations, as shown in **Figure 6.44**).
- Altering parking requirements
- Increasing building height limits

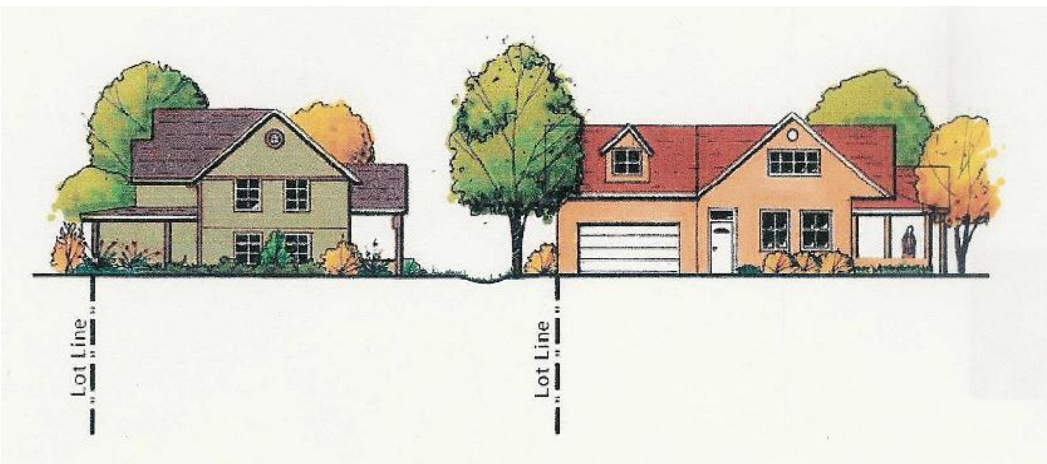


Figure 6.44. Zero Lot Line Configuration
Source: Puget Sound LID Technical Manual (2005)

Many of these changes are useful in reducing the amount of impervious cover on a development site (see Environmental Site Design Practices #12 through #17). A developer or site designer should consult their local review authority to determine whether the community supports PUD approvals. If so, the type and nature of deviations allowed from individual development requirements should be obtained from the review authority in addition to any other criteria that must be met to obtain a PUD approval.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
2.2: Use an integrated site development process	0 (Prerequisite)
4.4: Minimize soil disturbance in design and construction	6
4.5: Preserve all vegetation designated as special status	5
4.6: Preserve or restore appropriate plant biomass on the site	3 - 8
4.7: Use native plants	1 – 4
4.8: Preserve plant communities native to the ecoregion	2 – 6
4.9: Restore plant communities native to the ecoregion	1 – 5
4.10: Use vegetation to minimize building heating requirements	2 – 4
4.11: Use vegetation to minimize building cooling requirements	3 - 5
4.12: Reduce urban heat island effects	3 - 5

6.5.3. Reducing Impervious Cover in Site Design

The level of impervious cover – i.e. rooftops, parking lots, roadways, sidewalks and other surfaces that do not allow rainfall to infiltrate into the soil – is an essential factor to consider in ESD for stormwater management. Site by site and watershed by watershed, increased impervious cover means increased stormwater generation and increased pollutant loadings.

Thus by reducing the area of total impervious surface on a site, a site designer can directly reduce the volume of stormwater runoff and associated pollutants that are generated. It can also reduce the size and cost of necessary infrastructure for stormwater drainage, conveyance, and control and treatment. Some of the ways that impervious cover can be reduced in a development include:

- Reduce Roadway Lengths and Widths
- Reduce Building Footprints
- Reduce the Parking Footprint
- Reduce Setbacks and Frontages
- Use Fewer or Alternative Cul-de-Sacs
- Create Parking Lot Stormwater Islands

Figure 6.45 shows examples employing several of these principles to reduce the overall imperviousness of the development. The next several pages cover these methods in more detail.

Figure 6.45. Example of Reducing Impervious Cover (clockwise from upper left): (a) Cul-de-sac with Vegetated Island; (b) Narrower Residential Street; (c) Vegetated Median in Roadway; and (d) "Green" Parking Lot with Vegetated Islands
Source: ARC (2001)

6.5.3.1. Environmental Site Design Practice #11: Reduce Roadway Lengths and Widths

KEY BENEFITS	USING THIS PRACTICE
• Reduces the amount of impervious cover and associated runoff and pollutants generated • Reduces the costs associated with road construction and maintenance	• Consider different site and road layouts that reduce overall street length • Minimize street width by using narrower street designs that are a function of land use, density and traffic demand • Smaller side yard setbacks will reduce total street length
This practice reflects the CWP Better Site Design Principles #1 (Street Width), #2 (Street Length), and #3 (Right-of-Way Width)	

Figure 6.46. Narrow Residential Street with Swale Drainage
Source: Chesapeake Bay Stormwater Training Partnership

Roadway widths and lengths should be minimized on a development site where possible to reduce overall imperviousness, while still supporting expected traffic volume, on-street parking and access for emergency, maintenance and service vehicles. Furthermore, a wide right-of-way (ROW) is only needed when utilities and sidewalks are located some distance from the paved section of the roadway. While a wide ROW does not necessarily create more impervious cover, it can work against environmental site design for several reasons. First, it subjects a greater area to clearing during road construction. This may lead to needless loss of existing trees. Second, and more important, a wide ROW consumes land that may be better used for housing lots, making it more difficult to achieve a more compact site design. The right-of way in **Figure 6.46** above is just wide enough to account for the pavement and open channels. It is also narrower because there are no sidewalks and the utilities have been placed underground.

Consider the use of alternative road layouts (**Figure 6.47**) that increase the number of homes served per unit length, thus reducing the total linear length of roadways. This can significantly reduce overall imperviousness of a development site and associated runoff and pollutant generation. Reducing imperviousness also helps to reduce the urban heat island effect. Site designers are encouraged to analyze different site and roadway layouts to see if they can reduce overall street length. The length of local cul-de-sacs and cross streets should be shortened to a maximum of 200 ADT (average daily trips) to minimize traffic and road noise so that shorter setbacks may be employed.

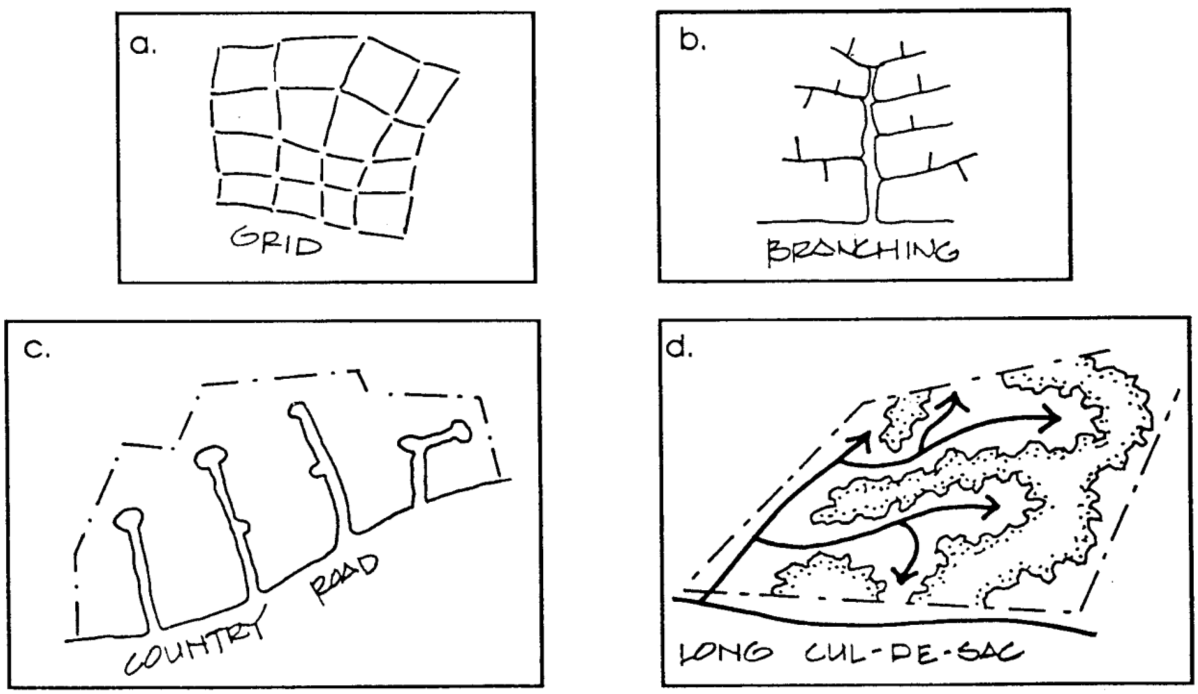


Figure 6.47. Alternative Street Layouts
Source: Center for Watershed Protection

Residential streets and private streets within commercial and other development should be designed for the minimum required pavement width needed to support travel lanes, on-street parking, and emergency access. Many communities require minimum street widths that are much wider than needed to support travel lanes, on-street parking, and emergency access. Access streets in subdivisions often are wider than the collector and "higher order" streets that receive their traffic. Ironically, excessively wide streets encourage excessive speed as well.

Several time-honored sources of highway specifications such as the American Association of State Highway and Transportation Officials (AASHTO) and the Institute of Transportation Engineers (ITE) have established minimum pavement width and right-of-way width specifications which are unnecessarily large, especially when applied in zones of lower density where average lot size is large and traffic generation, even at build-out, is much less than traffic anticipated by such specifications. **Table 6.13** below illustrates the various national standards as compared to alternative standards developed by the Metropolitan Washington (DC) Council of

Governments. For comparison, **Table 6.14** below is a translation of the most recent VDOT subdivision street design standards (March, 2009) into the same criteria categories.

Table 6.13. Condensed Summary of National Residential Street Design Standards

Design Criteria	AASHTO	ITE	MWCOG
Residential Street Categories	1	3	4 depending on ADT
Minimum Street Width	26 ft. min.	< 2du = 22-27 ft. 2-6 du = 28-34 ft. < 6du = 36 ft.	< 100 ADT = 16 ft. 100-500 ADT = 20 ft. 0-6 du/ac = 32 ft.
Additional righty-of-way	24 ft.	24 ft.	8 to 26 ft.
Design speed, level terrain	30 mph	30 mph	15 to 25 mph
Curb and Gutter	Generally required	Generally required	Not required on collectors
Cul-de-Sac Radii	30 ft.	40 ft.	30 ft.
Turning Radii in Cul-de-Sac	20 ft.	25 ft.	17 ft.
AASHTO = American Association of State Highway and Transportation Officials ITE = Institute of Transportation Engineers MWCOG = Metropolitan Washington Council of Governments (1995) ADT = Average Daily Trips Du = Dwelling Units			

Table 6.14. VDOT Residential Street Design Standards

Design Criteria	VDOT Curb & Gutter Street Section			VDOT Road & Ditch Street Section			
	No Parking	Parking 1 Side	Parking Both Sides	No Parking	Parking 1 Side	Parking Both Sides	Min. Width of Shoulder
Minimum Street Width	<2K ADT: 24 ft. 2-4K ADT: 26 ft.	<2K ADT: 24 ft. 2-4K ADT: 31 ft.	<2K ADT: 29 ft. 2-4K ADT: 36 ft.	<2K ADT: 24 ft. 2-4K ADT: 26 ft.	<2K ADT: 24 ft. 2-4K ADT: 31 ft.	<2K ADT: 29 ft. 2-4K ADT: 36 ft.	<2K ADT: 6 ft. 2-4K ADT: 8 ft.
Additional righty-of-way	8' to 12' from back of curb. Right-of-Way shall extend a minimum of 1' beyond any feature to be maintained by VDOT.			Minimum 28' beyond edges of pavement. Right-of-Way shall extend a minimum of 1' beyond any feature to be maintained by VDOT.			
Design speed, level terrain	<2K ADT: 25 mph 2K-4K ADT: 30 mph			<2K ADT: 25 mph 2K-4K ADT: 30 mph			
Curb and Gutter	Not required on collector streets						
Cul-de-Sac Radii	Circular Type Turnaround: 45 ft. to edge of pavement or face of curb Concentric or Offset Cul de Sac (unpaved center): Unpaved ctr area = min. 30 ft./max. 120 ft.						
Turning Radii in Cul-de-Sac	Minimum 45' radius to accommodate school buses, intercity buses and single unit trucks. Auto-TURN® shall be used when designing for larger vehicles.						
ADT = Average Daily Trips							

Source: Adapted from VDOT Road Design Manual, Appendix B(1): March, 2009

Even AASHTO's minimum pavement width of 26 feet is sometimes exceeded. For the type of "first order" street system designed to service low density residential subdivisions, this width is excessively costly to construct, requires expensive real estate, and creates far more stormwater than otherwise would result. Because of the way in which so much development is configured, these streets are often times just networks of cul-de-sacs specifically designed to exclude through traffic. In most cases such streets will not receive significantly increased traffic as an area builds out. Consequently, traffic levels are not likely to increase much beyond the traffic generated by the homes lining the street.

Width reduction offers considerable potential benefit in terms of stormwater reduction. For the very smallest access street or lane (approximately 15 homes, with fewer than 100 vehicle trips per day), width can be decreased to 16 feet. Guidelines exist to increase width as the traffic increases (20 feet for 100-500 trips per day, 26 feet for 500-3,000 trips per day, and so forth). In conventional developments with conventional lots and house design, there is no need to provide on-street parking, although if tightly clustered configurations are used, on-street parking may be a desirable option and included in the design (add another 8-foot lane).

Figure 6.48 below shows different options for narrower street designs. Many times on-street parking can be reduced to one lane or eliminated on local access roads with less than 200 ADT on cul-de-sac streets and 400 ADT on two-way loops. One-way single-lane loop roads are another way to reduce the width of lower traffic streets.

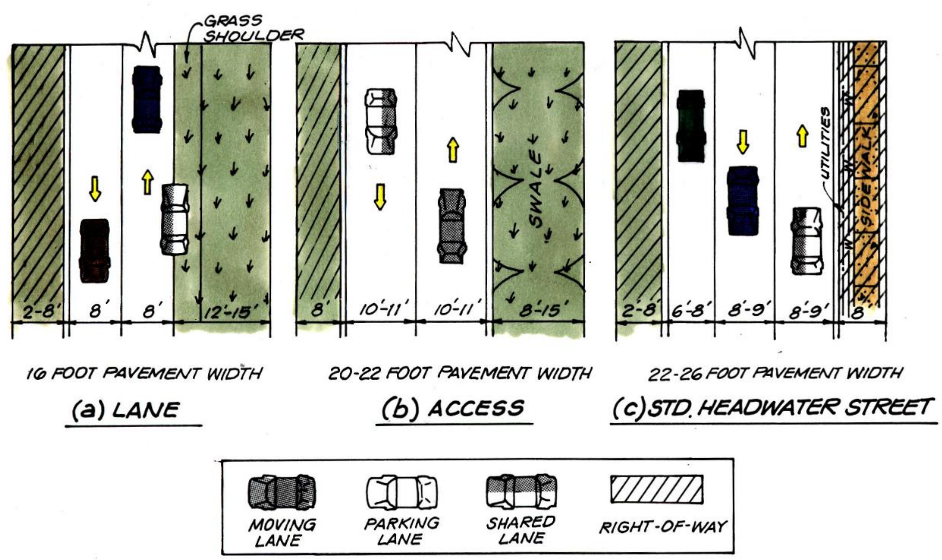


Figure 6.48. Potential Design Options for Narrower Street and Roadway Widths
Source: Chesapeake Bay Stormwater Training Partnership

Some communities currently require residential streets as wide as 32-40 feet and which provide two parking lanes and two moving lanes (**Figure 6.49** below). Local experience has shown that residential streets can have pavement widths as narrow as 22-26 feet, and still accommodate all access and parking needs (ITE, 1997). Even narrower access streets can be used when only a handful of homes are served. Significant cost savings occur in both road construction and maintenance. Narrower streets also help reduce traffic speeds in residential neighborhoods which, in turn, improve pedestrian safety. Snow stockpiles on narrow streets can be accommodated if parking is restricted to one side of the street or alternated between the sides. Alternatively, the right-of-way may be used for snow storage. Narrow snowplows are available.

Eight foot wide snowplow blades mounted on pick-up trucks are common. Some companies manufacture alternative snowplows on small Bobcat®-type machines.

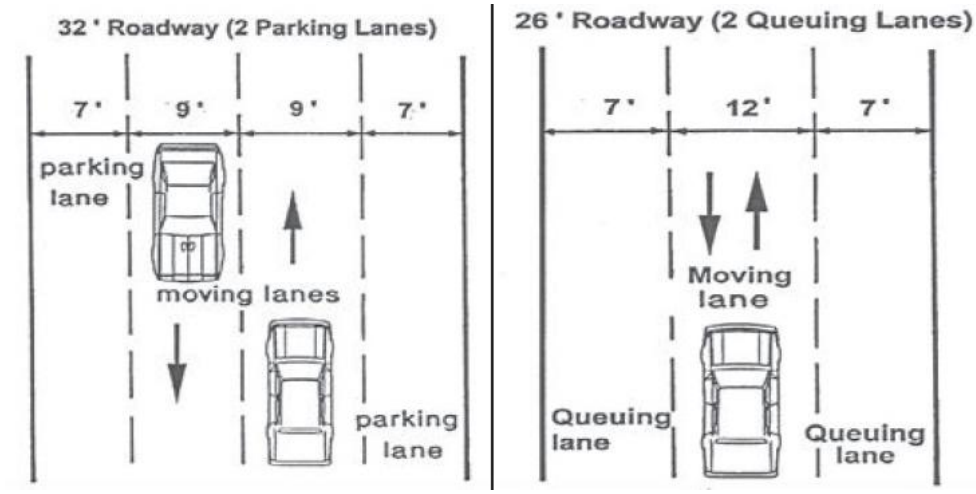


Figure 6.49. Traditional Street Width (left) and a Narrowed Street with "Queuing Lanes" (right). Source: MPCA (2006)

A narrower ROW can generally be accommodated on many residential streets without unduly compromising safety or utility access (see **Figure 6.50** and **Table 6.15** below). Some communities have recently narrowed ROWs for residential streets to 35-45 feet. This is done by redesigning each of the main components of the ROW. First, the *pavement width* is reduced on some streets. Second, *sidewalks* are either narrowed or restricted to one side of the street. Third, the *border width*, which separates the street from the sidewalk, is slightly relaxed. Last, *utilities* are installed underneath street pavement at the time of construction. When these design techniques are combined together, the width of most residential ROWs can be reduced to 10-25 feet. It should be noted that a narrow ROW may not be desirable if stormwater is conveyed by swales along the road (instead of curb and gutter).

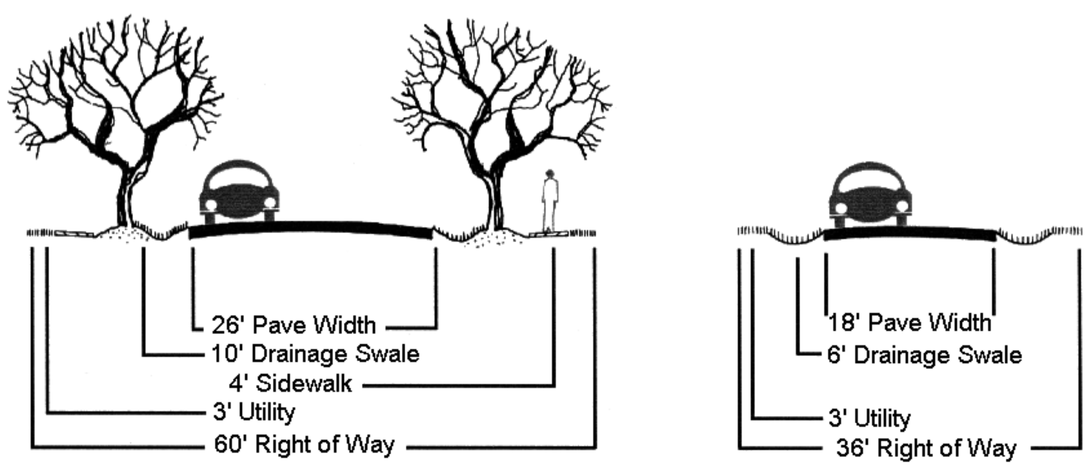


Figure 6.50. Design Options for Narrower Rights-of-Way on Residential Streets
(Source: VPI&SU, 2000)

Table 6.15. Examples of Narrower Right-of-Way Widths

Source	Right-of-Way Width	Pavement Width and Purpose
Portland, OR	35 feet 40 feet	20-foot residential street 26-foot residential street
Montgomery County, MD	20 feet 44 feet 46 - 60 feet	16-foot residential alley 20 foot residential street 26 foot residential street
ASCE, 1990 (Recommendations)	24 - 26 feet 42 - 46 feet	22 - 24 foot residential alley 26 foot residential street

Road length also is an important issue. Road length should first be addressed from a macro level planning perspective. Obviously overall dense patterns of development result in dramatically less road construction than low density patterns, holding net amount of development constant. High density development and vertical development contrast sharply with low density sprawl, which has proliferated in recent years and has required vast new highway systems throughout urban fringe zones.

Furthermore, if the critical mass of density is achieved, other forms of transportation such as transit may be enabled. Concepts such as Transit Oriented Development (TOD) has extremely important stormwater benefits as well, where **f**lows of all types – from stormwater to traffic – can be managed much better. The Department encourages the Virginia Department of Transportation (VDOT) to continue to consider appropriate revisions in its standards for subdivision roads and streets – which govern design criteria in most Virginia communities – to minimize street size and imperviousness while still maintaining traffic and pedestrian safety.

More detailed guidance about minimizing street imperviousness can be found in the discussion of Principles No. 1 (Street Width), No. 2 (Street Length), and No. 3 (Right-of-Way Width) in CWP 1998a.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.12: Reduce urban heat island effects	3 - 5

6.5.3.2. Environmental Site Design Practice #12: Reduce the Impervious Footprints

KEY BENEFITS	USING THIS PRACTICE
• Reduces the amount of impervious cover and associated runoff and pollutants generated • Can result in slowing/calming traffic in residential neighborhoods	• Use alternate or taller building designs to reduce the impervious footprint of buildings • Consolidate functions and buildings or segment facilities to reduce footprints of structures • Reduce directly-connected impervious areas
This practice reflects the CWP Better Site Design Principles #13 (Sidewalks) and #14 (Driveways)	

Building Footprints

The impervious footprint of commercial buildings and residences can be reduced by using alternate or taller buildings while maintaining the same floor to area ratio. Sidewalk and driveway lengths and widths should be minimized where possible to reduce overall imperviousness. Reducing imperviousness also helps to reduce the urban heat island effect.

In order to reduce the imperviousness associated with the footprint and rooftops of buildings and other structures, alternative and/or vertical (taller) building designs should be considered. Consolidate functions and buildings, as required, or segment facilities to reduce the footprint of individual structures. **Figure 6.51** shows the reduction in impervious footprint by using a taller building design.

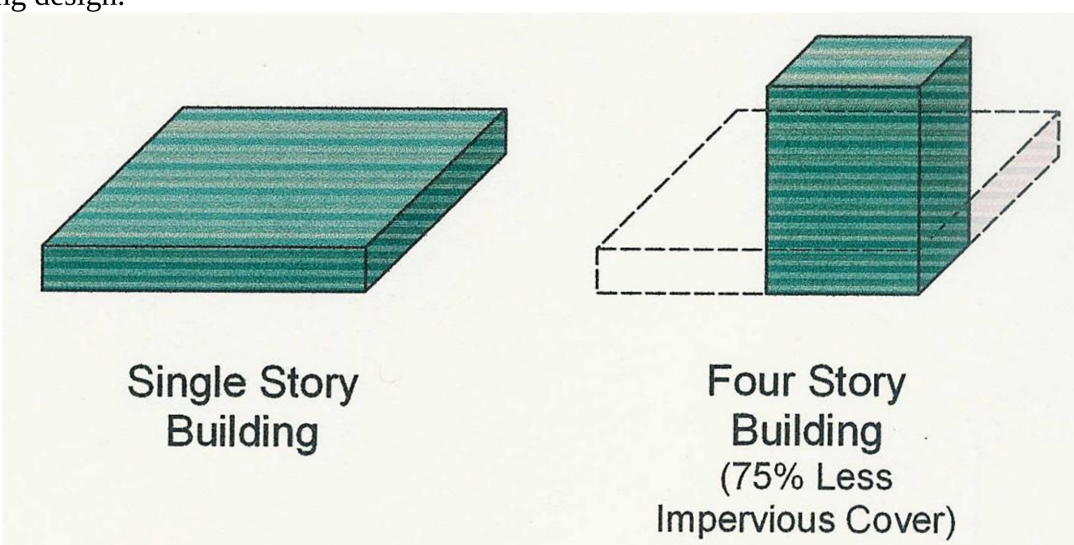


Figure 6.51. Building Up Rather Than Out Can Reduce the Amount of Impervious Cover on the Site. Source: ARC (2006)

Sidewalk Footprints

Many communities require sidewalks that are excessively wide or are located adjacent to the street where the pedestrians are at risk from vehicles. While sidewalk design requirements protect pedestrians, needless sidewalks can also increase the amount of site imperviousness, thereby preventing infiltration of stormwater runoff into the soil. In general, the placement and width of sidewalks can be modified without impairing travel access or minimizing pedestrian safety.

An environmental site design technique modifies the width and location of sidewalks to promote safer pedestrian mobility when linking pedestrian areas (**Figure 6.52**). Impervious cover is reduced when sidewalks are required on only one side of the street, reduced in width (to 3 or 4 feet) and are located away from the street. Sidewalks can also be disconnected so they drain to lawns or landscaping instead of the gutter and storm drain system. Slimmer sidewalks reduce and/or disconnect impervious cover, and thus reduce the generation of runoff. However, a minimum width of 4 feet should be provided, pursuant to the Americans with Disabilities Act. Other benefits include greater pedestrian safety, lower construction and maintenance costs, and reduced individual homeowner responsibility for snow clearance.

Figure 6.52. A Common Walkway Draining to Adjacent Vegetation and Linking Pedestrian Areas
Source: MPCA (2006)

Pedestrian safety is the usual reason for requiring sidewalks on both sides of a street. However, actual safety statistics show that having a sidewalk on only one side of the street provides approximately the same level of safety as providing sidewalks on both sides of the street (**Table 6.16** below).

Table 6.16. Survey of Pedestrian Accidents Related to the Presence of Sidewalks

Sidewalk Location	% of Accidents
No sidewalk present	83.5%
Pedestrian sidewalk only	0.9%
Multi-use sidewalk	0.6%
Sidewalk present on both sides of street	7.3%
Sidewalk present on at least one side of street	7.7%
Total	**100%**

Source: NHI (1996)

While safety is probably the most important issue governing pedestrians and the use of sidewalks, more and more governments, well-insured organizations, and professionals are being sued as a result of accidents involving pedestrians. It is true that taking simple and straightforward steps can reduce the occurrence of legal challenges and reduce the liability involved. The most important factor involving a government official or design professional in protecting themselves from legal challenges is the use of "ordinary care." Ordinary care means that design decisions are based on a basic level of care that can be expected of a reasonably experienced and prudent professional. Ordinary care is usually determined by using the "85 percentile rule." This simply means that designs are based on accommodating the behavior that can be expected of 85 percent of the travelers who use the facility in a reasonable manner (NHI, 1996). **Table 6.17** provides recommended design elements for sidewalks.

Table 6.17. Design Elements for User-Friendly, Safe and Legally Defensible Sidewalks

Sidewalk Design Element	Use, Safety, and Liability Considerations
4 feet minimum width	Allows users to walk side-by-side, helping to keep one user from walking in the street
Provide a buffer from traffic	Limits potential accidents and resulting lawsuits
Provide access to streets and destinations	Provides linkage between automobiles, transit and other destinations, avoids "dumping" pedestrians out at unsafe locations
Provide shade where possible	Makes walking more pleasant in the heat of summer
Design to avoid areas of standing or flowing water across the sidewalk	Standing or flowing water can freeze in the winter, creating a hazard and a potential liability situation
Design at the street level	Encourages sidewalk use and awareness of traffic situations
Limit the amount and strictly regulate vending machines (e.g., news stands, FedEx boxes, etc.)	These items take up valuable sidewalk space, potentially hinder sight distances, and can infringe on sidewalk area at critical locations, such as road crossings
Provide places to sit	Provides rest spots and places for people to stop, out of the way of traffic and congestion
Provide adequate and well-designed crossings	Helps minimize one of the major reasons for pedestrian accidents (i.e., darting out in front of on-coming traffic)

Source: Partially adapted from NHI, 1996

The Americans with Disabilities Act (ADA) does not specifically address sidewalks. However, it does require accessible routes. There must be at least one accessible route within the site boundary from public transportation stops, parking, and passenger loading zones. There must be at least one accessible route from public streets or sidewalks to the buildings or facilities they serve. Accessible routes must coincide with the routes for the general public *to the maximum extent feasible.* Sidewalks must be at least three feet wide (ADA Hotline, 1997; Dey, 1997).

Driveway Footprints

Driveways are linked very much to the configuration of a development and present another opportunity to practice environmental site design. Most local codes contain front yard setback requirements that dictate driveway length. In many communities, front yard setbacks for certain residential zoning categories may extend 50 or 100 feet or even longer. This increases driveway length well beyond what is needed for adequate parking and access to a garage. Furthermore, as lots have grown larger (sometimes much larger than one acre), minimum setback criteria typically are exceeded significantly. Houses often sit back considerable distances; driveways and total impervious cover increase significantly. As much as 20 percent of the impervious cover in a residential subdivision consists of driveways (Schueler, 1995).

As houses have grown larger and car-per-household ratios have increased, greater accommodation has been required for the automobile, which translates into increased impervious surface of different types. A 20-foot driveway fans out into a three-car garage. Turnaround aprons are increased in size accordingly. More aesthetic side-loading garages mean even longer driveways. The end result has been a substantial increase in the amount of impervious area created per person or per dwelling.

Shorter setbacks reduce the length and impervious cover for individual driveways. In addition, driveway width can be reduced from 20 feet to 18 feet, and more permeable driveway surfaces allowed (**Figure 6.53**). Another way to reduce impervious cover is to allow shared driveways (with enforceable maintenance agreements and easements) that provide street access for up to six homes (**Figure 6.54** below). Shorter driveways help reduce infrastructure costs for developers since they reduce the amount of paving or concrete needed. Another option, intrinsic to Traditional Neighborhood Design (TND), is the elimination of the driveway altogether, as garages open onto alleys – the new common driveways – with small aprons.

Figure 6.53. Alternative (Permeable) Driveway Surfaces
Source: ICPA

Figure 6.54 Example of a Shorter Driveway (left) and a Shared Driveway (right)
Source: MPCA (2006)

Minimize Clearing of Existing Vegetation

Last, but certainly not least among techniques to minimize building footprints is the concept of minimizing the amount of landscape that is cleared and will require maintenance following development. Ideally, clearing of vegetation and disturbance of soil is carefully limited to a prescribed distance from proposed structures and improvements (see **Section 6.5.2.3**, ESD Practice #8). At issue are construction phase impacts as well as long-term operation and maintenance of the development. The objective should be to maximize existing (hopefully natural/native) vegetation and to minimize creation of an artificial landscape that will perpetually require chemical nutrients and routine cutting/trimming.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.12: Reduce urban heat island effects	3 - 5

6.5.3.3. Environmental Site Design Practice #13: Reduce the Parking Footprints

KEY BENEFITS	USING THIS PRACTICE
• Reduces the amount of impervious cover and associated runoff and pollutants generated	• Reduce the number of parking spaces • Minimize stall dimensions • Consider parking structures and shared parking • Use alternative porous surface for overflow areas
This practice reflects the CWP Better Site Design Principles #6 (Parking Ratios), #7 (Parking Codes), #8 (Parking Lots), #9 (Structured Parking, and #10 (Parking Lot Runoff)	

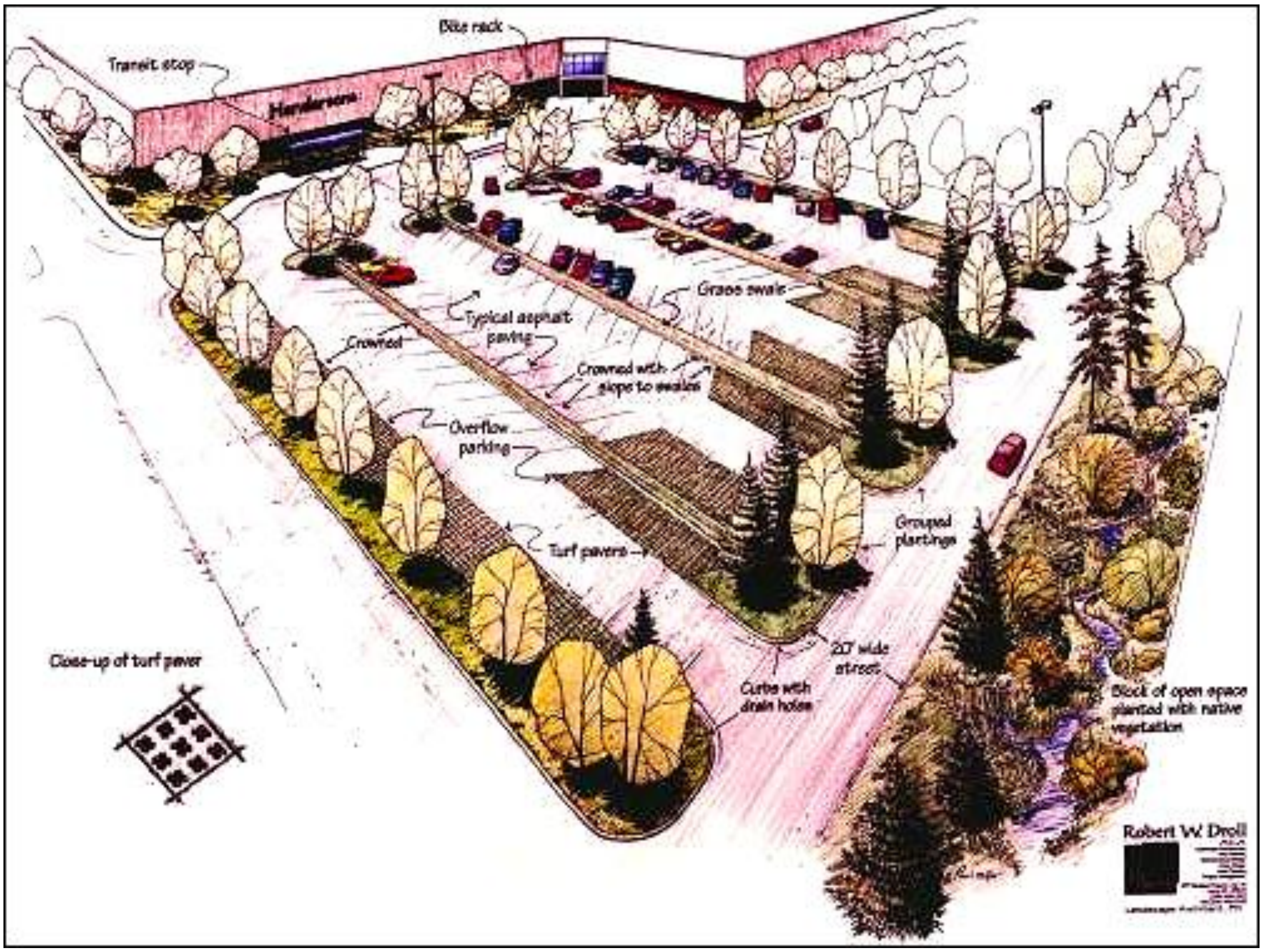


Figure 6.55. Multiple Stormwater Management Strategies Applied to Parking Lot
Source: Chesapeake Bay Stormwater Training Partnership

Stormwater management requirements can be met in many cases by applying environmental site design principles to parking lot design. Overall imperviousness associated with parking lots can be reduced by eliminating unneeded spaces, providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, using multi-storied parking decks, and using permeable pavers or pavement surfaces in overflow parking areas, where feasible, to reduce and treat stormwater runoff. Reducing imperviousness and replacing it with valuable green space also helps to reduce the urban heat island effect.

A complete discussion of all of the relevant parking/stormwater issues links to larger macro planning issues quite quickly. Stated simply, low density development sprawling into the countryside – widely scattered subdivisions, office parks and shopping centers along major roadways and at expressway interchanges – typically forces maximum reliance on the automobile for transportation. This means more trips will be generated on a per-resident or per-capita basis, so there is a need for more parking accommodations. By contrast, with Transit Oriented Design (TOD) or Traditional Neighborhood Design (TND), the total number of auto trips is reduced as the result of walking, biking or using available transit services, so parking needs are reduced. Furthermore, the mixture of uses as found in these neo-traditional TOD/ TND configurations also means that opportunity for creative "sharing" of spaces can be devised so that daytime spaces can be used for nighttime parking demand as well. This minimizes the suburban separation of uses with its vast zones of single-purpose parking lots. Additionally, this blending of uses and sharing of parking spaces can help to deflect the peak demand factor (i.e., the shopping mall at Christmas) that has driven so many municipal parking requirements. But there are also ESD techniques that can minimize parking-related imperviousness, even when more conventional modes of development are used.

For example, the aerial photo in **Figure 6.56** below shows a parking lot in Minneapolis, Minnesota. The University of Minnesota's Metropolitan Design Center redesigned the lot to demonstrate how impervious area can be reduced while maintaining the same number of required parking spaces. **Figure 6.57** is a graphic of the parking lot as originally designed, showing that the drive aisles and several of the parking spaces in the lot *exceed* the city's minimum parking requirements. The drive lanes are 28-feet wide. However, the city requires a minimum of 22 feet for two-way driving lanes and 20 feet for one-way lanes in parking lots with 90^{o} parking stalls. The green spaces do not effectively capture stormwater runoff and the trees do not shade the parking lot.

Figure 6.58 shows the redesign. By reducing the interior driving lanes to 20-feet wide and increasing the percentage of compact spaces, green space can be increased to 22 percent. Effective use of the minimum parking space and aisle dimensions as permitted in the city's zoning code allows the number of parking spaces to remain the same, while adding valuable green space to the parking lot.

Figure 6.56. Original Parking Lot. Source: Philadelphia Stormwater Manual

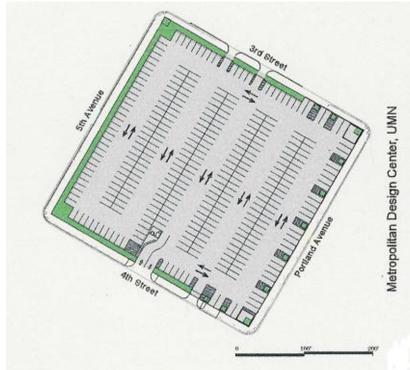


Figure 6.57. Original Design
Source: Philadelphia Stormwater Manual

255 standard parking spaces
70 compact parking spaces
325 total parking spaces
Total green space: 6.5%

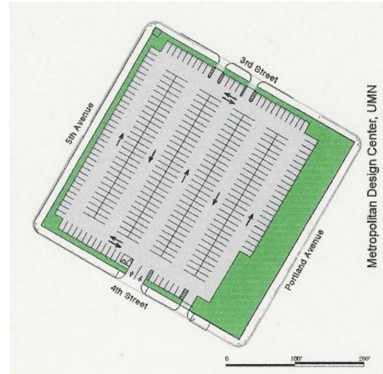


Figure 6.58. Redesigned Lot
Source: Philadelphia Stormwater Manual

244 standard parking spaces
81 compact parking spaces
325 total parking spaces
Total green space: 22%

The bottom line is that smaller parking lots can sharply reduce impervious cover and provide more effective treatment of stormwater pollutants. In addition, smaller parking lots reduce both up front construction costs and long term operation and maintenance costs, as well as the size and cost of stormwater practices. Parking lot landscaping makes the lot more attractive and comfortable for customers, and promotes safety for both vehicles and pedestrians. In addition, trees and other landscaping help screen adjacent land uses, shade people and cars, reduce summertime temperatures and improve air quality and bird habitat. In many communities, parking lots are over-sized and under-designed. Local parking and landscaping codes can be modified to allow the following ESD techniques to be applied within parking lots:

- Minimize standard stall dimensions for regular spaces
- Provide compact car spaces
- Use of pervious pavement (asphalt, concrete, blocks, sand amendments)
- Incorporate efficient parking lanes
- Reduce minimum parking demand ratios for certain land uses
- Treat the parking demand ratio as a maximum limit (rather than a minimum, which can be increased arbitrarily)
- Create stormwater "islands" in traffic islands or landscaping areas to treat runoff using bioretention, filter strips or other practices
- Encourage shared parking arrangements
- Use structured parking

Parking Space Ratios

Many localities rely on parking ratio standards prepared by recognized agencies and authorities. The common practice is to set parking ratios to accommodate the highest hourly parking need during the peak season. The trend in recent years has been to increase these ratios, perhaps reflective of the general increase in land development and traffic and congestion and the concern on the part of most localities to err on the conservative side. In some cases, minimum parking requirements are actually exceeded by the developer interested in promoting business. Municipalities typically establish *minimum* parking ratios, but rarely establish *maximum* parking ratios (the maximum possible number of spaces *allowed to be built* at a project). This typically results in parking lot designs with far more spaces than are actually required, where the vast majority of parking spaces are unused most of the time. By determining average parking demand instead, a lower maximum number of parking spaces can be set to accommodate most of the demand. **Table 6.18** provides examples of conventional parking ratio requirements and compares them to average parking demand. **Figure 6.59** below shows the variation in parking space sizes across the nation.

Table 6.18. Conventional Minimum Parking Ratios

Land Use	**Parking Requirement**		**Actual Average Parking Demand**
	Typical Parking Ratio	**Typical Range**	
Single family homes	2 spaces per dwelling unit	1.5 – 2.5	1.11 spaces per dwelling unit
Shopping Centers	5 spaces per 1000 sq. ft. gross *floor* area (GFA)	4.0 – 6.5	3.97 per 1000 sq. ft. GFA
Convenience Store	3.3 spaces per 1000 sq. ft. GFA	2.0 – 10.0	--
Other Retail	4 spaces per 1000 sq. ft. GFA	--	--
Restaurant	1 space for 50 sq. ft. of gross *leasable* area	--	--
Industrial	1 space per 1000 sq. ft. GFA	0.5 – 2.0	1.48 per 1000 sq. ft. GFA
Professional Office	5 spaces per 1000 sq. ft. GFA	4.5 – 10.0	4.11 per 1000 sq. ft. GFA
Church	1 space per 5 seats	--	--
Golf Course	4 spaces per hole	--	--
GFA – Gross floor area of a building, not counting storage or utility spaces			

Source: Adapted from CWP (1998a) and Chesapeake Bay Stormwater Training Partnership

The first parking-related objective of ESD is to avoid inflated parking ratios. All parking requirements should be revisited, compared with neighboring municipalities, and compared with actual experience. In the ideal, a study of actual developments and their respective experiences should be undertaken. However, elaborate studies can be circumvented by quick phone calling and other creative ways to assess the local situation. Ratios such as the typical 5 spaces per 1,000 square feet of gross leasable floor area should be downwardly adjusted as much as possible. Depending upon the specific use involved, ratios driven by peak demand such as for shopping centers may be able to be further reduced if combined with special parking overflow provisions.

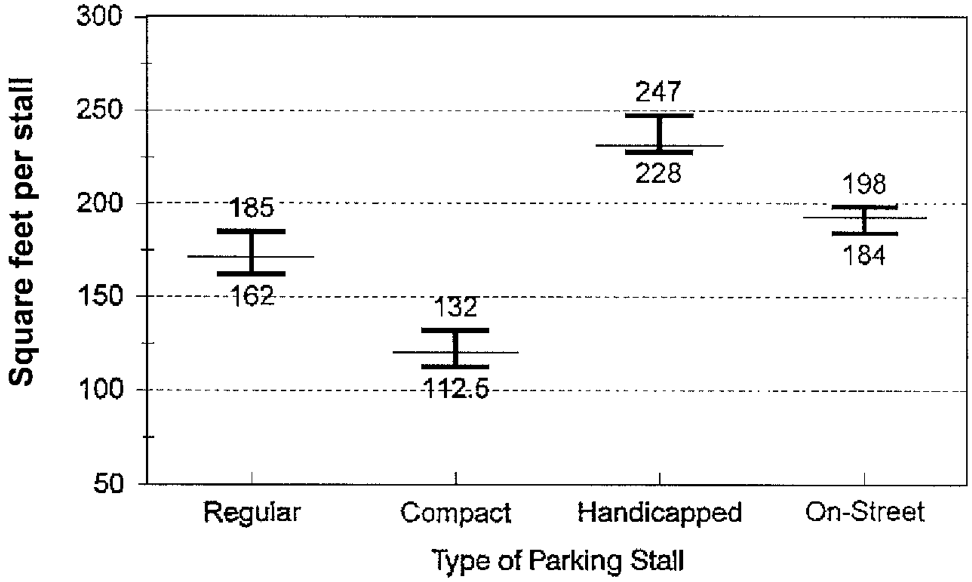


Figure 6.59. Variation in Parking Space Sizes Across the U.S.
Source: Schueler (1995)

However, it is important that adjustment of ratios is done with care. Some office parks, for example, are experiencing "employment intensification" which is certainly compatible with many growth management principles being espoused nationally. As companies grow, more employees typically are hired (downsizing excepted); and ratios of employees per square foot of work area increase. Therefore, cars usually increase, along with the demand for more parking.

In light of this, communities should re-evaluate their parking demand ratios based on local surveys of actual parking lot use rates for a mix of common land uses or activities. Localities should also make it clear that their parking ratios should be interpreted as the *maximum* number of spaces that can be built at a project, unless compelling data justify that more parking spaces are actually needed (based on actual parking demand studies). Reducing parking spaces to numbers reflecting actual use can also reduce construction costs significantly. Costs per space ranged from $1,200 to $1,500 in 1995 (Markowitz). Reducing a commercial parking ratio from 5 spaces to 4 spaces per 1,000 square feet of gross floor area could result in savings of tens of thousands of dollars, even then. Savings would likely be much greater today.

Parking Stall and Aisle Dimensions

Parking lots are the largest component of impervious cover in most commercial and industrial zones, but conventional design practices do little to reduce the paved area in parking lots. The size of a parking lot is driven by stall geometry, lot layout and parking ratios. A parking space is composed of five impervious components, of which the stall is only one part:

- The overhang at the edge of the stall (beyond the car)
- A narrow curb (or curb stop)
- The parking stall
- The parking aisle that allows access to the stall; and
- A share of the common impervious area (e.g., fire lanes, entrances, and traffic lanes)

In terms of parking stall design standards, parking stall size can be reduced without compromising performance of the parking lot. In most parking codes, stall size itself can range from 162 to 200 square feet. A standard dimension in years past has been approximately 10-by-20 feet, borne out of the large car era. Schueler, assuming a 9.5-by-19 foot space dimension further points out that with the typical overhang zone provided plus the appropriate share of the parking aisle, this parking space impervious area increases to 400 square feet, nearly twice the area of the parking stall itself (see **Figure 6.60** below).

With the downsizing of vehicles, even full size vehicles such as SUVs, a reasonable size adjustment to the parking stall would be 9-by-18 feet, nearly a 20 percent reduction in impervious area lot-by-lot, or even 7.5-by-15 feet for compact stalls (a reduction of nearly 50 percent), which comprise 40-50 percent of all cars on the road. A fixed percentage of these compact stalls should be specified (perhaps 20 to 35 percent of the total number of stalls, depending upon use, local experience, etc.).

Another component of the lot layout is the internal geometry or traffic pattern. The traffic flow of the parking lot design can be optimized to eliminate unneeded lanes (drive aisles). For example, two-way traffic aisles require greater widths than one-way aisles (for example, from 24 to 18 feet). One-way aisles used in conjunction with angled parking stalls can significantly reduce the overall size of the parking lot. Depending upon the size and configuration of the parking lot, total impervious area of the parking lot may decrease by as much as 10 percent.

Structured Parking

Most communities do not specify the type of parking structure to be built (e.g., surface lot or parking garage). The type of parking facility constructed in a given area is a reflection of the cost of land and construction expenses. In suburban and rural areas, where land is relatively inexpensive, surface parking costs much less than a parking garage. However, in highly urban areas with higher land costs, multi-deck garages may be more economical per car space than open lots. Also, if neo-traditional TND/TOD concepts are put into practice, densities can be increased sufficiently so that structured parking can make economic sense. Structured parking decks are one method to significantly reduce the overall impervious area footprint. **Figure 6.61** below shows a parking deck used for a commercial development.

Local governments should consider providing incentives (e.g., tax credits, stormwater waivers, or density, floor area, or height bonuses) to encourage the construction of multi-level, underground, and under-the-building parking structures. In this manner, developers can reduce the land cost chargeable to parking.

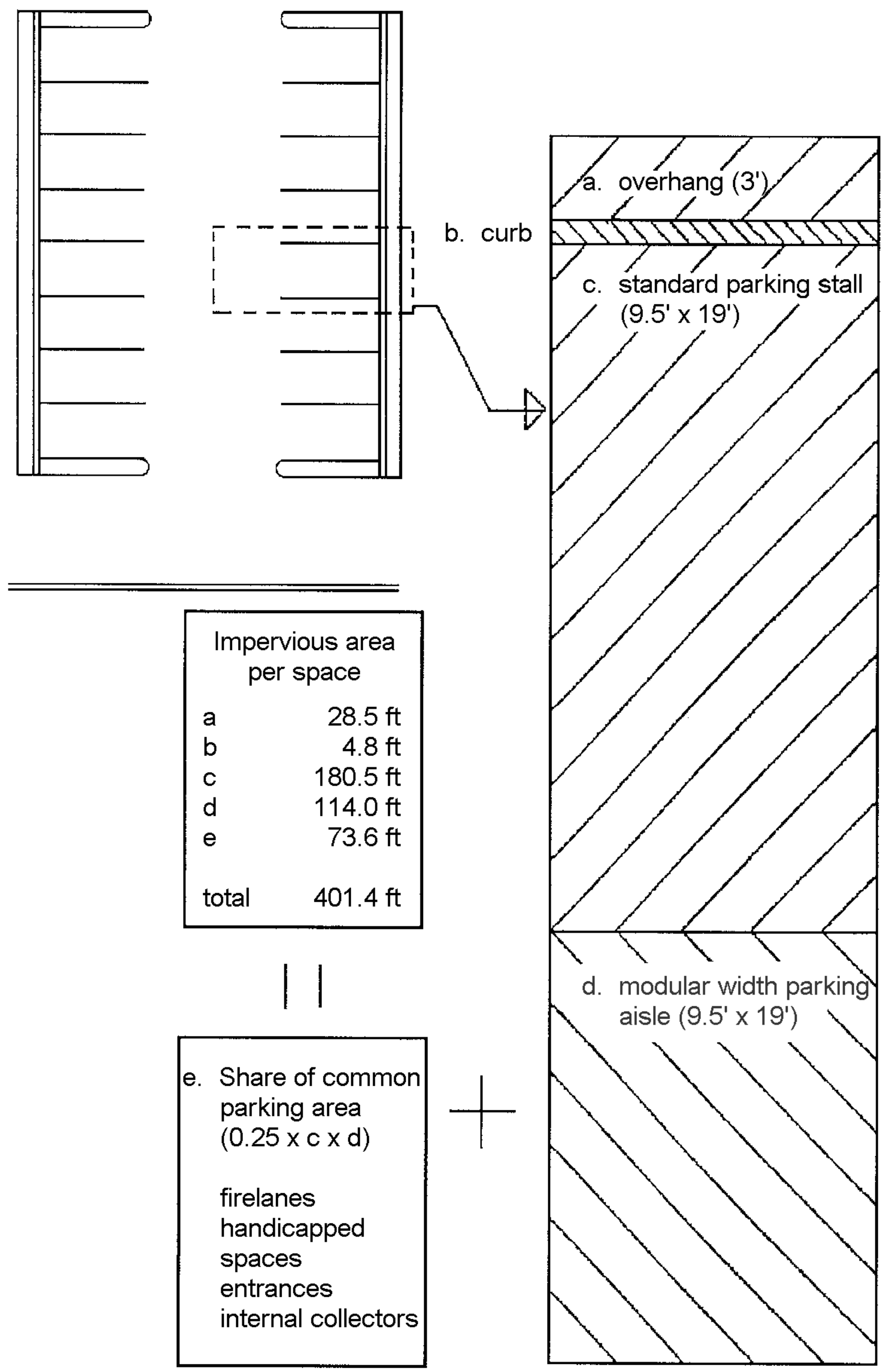


Figure 6.60. Parking Stall Dimension Analysis
(Source: Schueler, 1997)

Figure 6.61. Structured Parking at an Office Park Development
Source: ARC (2001)

Shared Parking Spaces

Depending on site conditions (i.e., proximity to mass transit or a mix of land uses), it is possible to reduce the number of parking spaces needed. Parking can be shared in mixed-use areas by creatively pairing uses wherever possible, especially when the adjoining parking demands occur and different times during the day or week (see **Table 6.19**). A shared parking arrangement could include usage of the same parking lot by an office space that experiences peak parking demand during weekdays with a church that experiences parking demands during the weekends and evenings.

Table 6.19. Land Uses with Different Peak Daily Operating Times

Land Uses with Daytime Peak Hours	Land Uses with Evening Peak Hours
Banks	Bowling Alleys
Business Offices	Hotels (without conference facilities)
Professional Offices	Theaters
Medical/Dental Clinics	Restaurants
Service Stores	Bars
Retail Stores	Night Clubs
Manufacturer/Wholesale	Auditoriums
Grade Schools/High Schools	Meeting Halls

Source: CWP (1998a)

Mass transit (light rail, transit buses, etc.) can lower parking demand directly by reducing the number of vehicles driven and, therefore, the number of vehicles that need to be parked. Furthermore, mass transit is a key strategy for reducing traffic congestion and air pollution.

Developers often don't even attempt such sharing because of the perception that officials would simply reject the concept. Municipalities should incorporate such sharing concepts into their requirements. There are straightforward guidelines which can be used to make sharing operate reasonably. Localities should even consider providing incentives for developers to use sharing options. Sharing is another effective way to reduce parking demand and impervious surfaces.

Alternate (More Permeable) Parking Area Surface Materials

A variety of other design-linked techniques should be evaluated, including altered approaches to spillover parking where pervious pavement approaches can be used. Gravel in these rarely used zones should be considered, or perhaps some version of grid pavers (several types are now available). Even grass may be a possible option. Pervious paving materials are usually less durable than asphalt, but they are appropriate for less traveled spillover areas.

Figures 6.62 and 6.63 below are examples of porous paver used at overflow parking areas. Alternative pavers can also capture and treat runoff from other site areas. However, porous pavement surfaces generally require proper installation and more maintenance than conventional asphalt or concrete. For more specific information using these alternative surfaces, see the Specification for *Permeable Pavement* on the Virginia Stormwater BMP Clearinghouse web site at: http://www.vwrrc.vt.edu/swc/ .

Construction costs for permeable pavement materials are generally higher than for conventional pavements. However, cost savings due to reduced curb and gutter and reduced stormwater management requirements can offset this initial cost difference. Similarly, reduced storm sewer and stormwater management facility maintenance requirements may offset the generally greater maintenance requirements associated with permeable pavement.

Figure 6.62. Grass Paver Surface Used for Parking
Source: ARC (2001)

Figure 6.63. Other Options for Permeable Surfaces in Fringe Parking Areas
Source: Cahill & Associates

Incorporation of Additional Parking Lot Stormwater Control Measures

Parking lots are significant sources of stormwater pollutants in the urban/suburban landscape, particularly in commercial areas. These large impervious areas also generate significant volumes of stormwater runoff, which typically carries the pollutants into nearby streams. *During the design stage*, parking lot layout and BMP choice are two linked and important considerations for an effective design. The most practical layout should be chosen for the lot. The BMPs used in the design should be located at the lowest point(s) of elevation of the parking lot. Whenever possible, plan to integrate bioretention areas, filter strips, and permeable paving materials into parking lots and required landscaping areas and traffic island. These practices will remove pollutants and infiltrate much of the runoff into the ground, rather than merely transferring it into local surface waters. The application of green parking techniques in various combinations can dramatically decrease times of concentration and detention times of a site. Reducing the volume of runoff discharged into receiving streams and stretching out the time during which it is discharged also helps to protect the structural and biological integrity of the receiving channels.

The two photos below (**Figure 6.64** below) show the parking lot of a public school in Portland, Oregon. The school used a better layout to increase the number of spaces available and to capture the runoff and treat and infiltrate it through vegetated infiltration beds (e.g., Virginia Stormwater Design Specification No. 10, Bioretention, or Virginia Stormwater Design Specification No. 11, Dry Swale). **Figure 6.65** below shows a grass channel receiving runoff from a parking area, and **Figure 6.66** below shows a more robust bioretention installation in a parking area median.

Figure 6.64. Glencoe Elementary School Parking Lot (Before and During Storm), Portland, Oregon
Source: Philadelphia Stormwater Manua

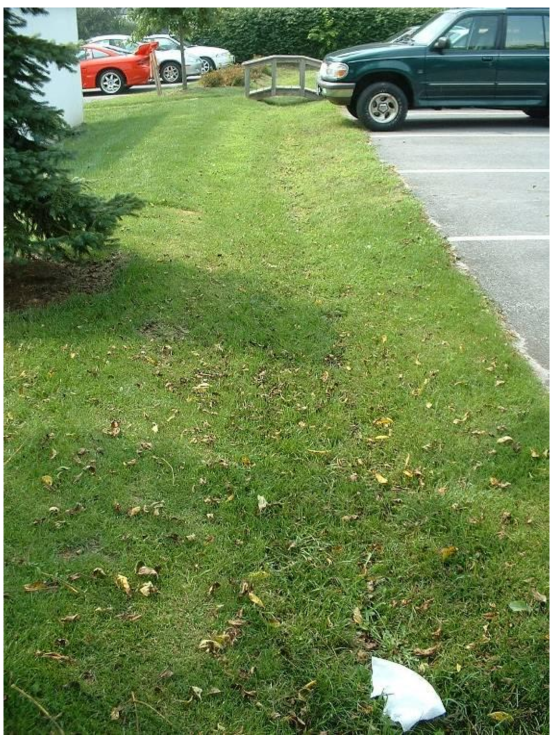


Figure 6.65. Grass Channel Receiving Parking Lot Runoff. Source: CWP

Figure 6.66. Bioretention in Parking Median.
Source: Center for Watershed Protection

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9
4.12: Reduce urban heat island effects	3 - 5

6.5.3.4. Environmental Site Design Practice #14: Reduce Setbacks and Frontages

KEY BENEFITS	USING THIS PRACTICE
• Reduces the amount of impervious cover and associated runoff and pollutants generated	• Reduce building and home front and side setbacks • Consider narrower frontages
This practice reflects the CWP Better Site Design Principle #12 (Setbacks and Frontages)	

Many subdivision codes have very strict requirements that govern the geometry of the lot. These include side yard setbacks, minimum lot frontages, and lot shape (see **Figure 6.67**). Although the precise requirements vary from locality to locality, most localities require structures, especially residences, to be set back specific distances from street and highway rights-of-way, which are typically somewhat landward of the edge of the street to begin with. Structures typically must be set back from lot lines on the side and rear as well, all of which effectively requires lots to be quite large. Similarly, yard requirements (front, side, and rear) often are comparably overstated. Typically, lot-by-lot street frontage requirements are excessive, making concentrated development configuration difficult or impossible. From this perspective, such setbacks must be viewed as contrary to the goals and objectives of ESD.These criteria constrain and, in some cases, prevent site planners from designing open space or cluster developments that can reduce impervious cover.

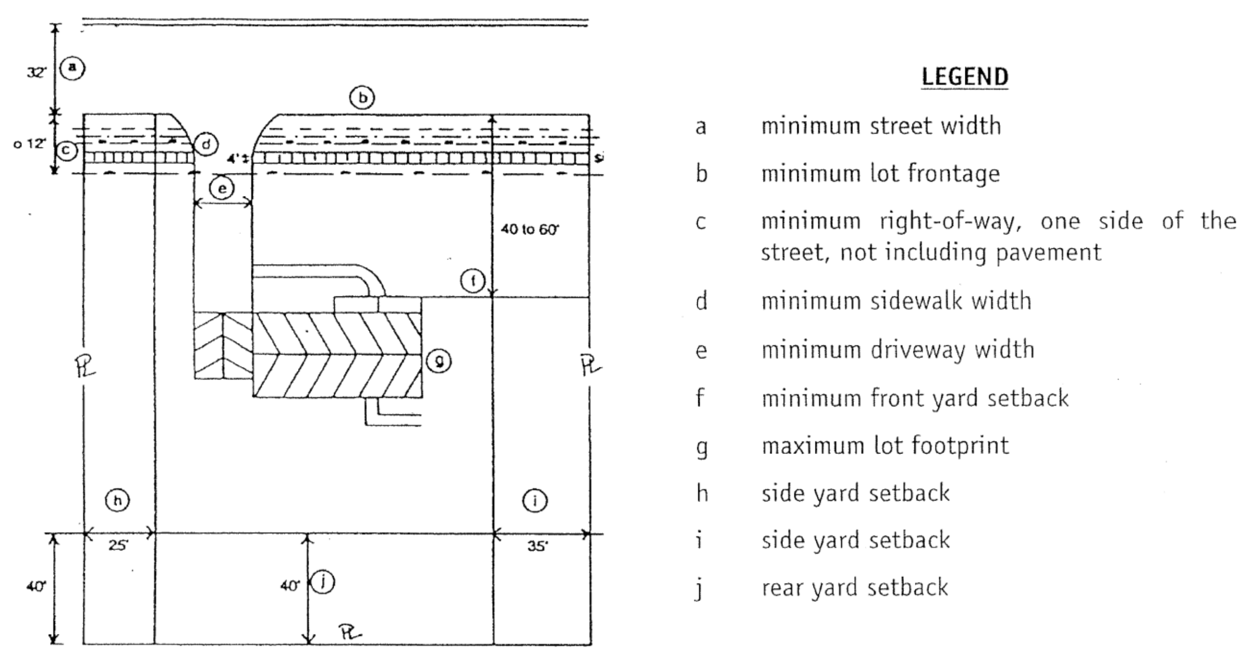


Figure 6.67. Setback Geometry of a Typical 1-Acre Lot
Source: Schueler (1995)

Setbacks and frontage distance requirements can increase impervious cover in the following ways:

- Front yard setbacks, which dictate how far houses must be from the street, can extend driveway length.
- Large side setbacks and frontage distances (usually larger as housing density increases) directly influence the road length needed to serve individual lots.

Smaller setbacks and frontage distances, which are often essential for open space designs, are typically not permitted or require a zoning variance, which may be difficult to obtain.

Setbacks and frontage widths have evolved over time and have been used in local jurisdictions to satisfy a variety of community goals. Often setback and frontage distances are used to ensure uniform appearance and equally-sized lots. Setbacks are often used for fire safety purposes (i.e., to prevent fire from spreading from forests to a house or from one house to another) and traffic concerns. Frontage distances are often set to provide for residential parking. The availability of on-street parking is largely determined by the street length serving each lot, which is set by minimum frontage distance.

Reduction in setbacks is integral to clustering and reducing imperviousness. Communities can reduce impervious cover by relaxing or reducing front and side yard setbacks and allowing for narrower frontage distances. Allowing for narrower side yard setbacks leads to narrower lot widths. With narrower lots, shorter roads are needed, which reduces overall imperviousness. Relaxing front yard setbacks leads to shorter front yards. This eliminates the need for long driveways, which are found in many conventional subdivisions. Flexible setback and frontage requirements allow developers to be creative in producing attractive and unique lots, more interesting neighborhood aesthetics, and more compact lots that provide sufficient room for personal living and recreation while still creating common open space areas. This can allow the flexibility to preserve open space on the development site.

Building and home setbacks should be shortened to reduce the amount of impervious cover from driveways and entry walks. A setback of 20 feet is more than sufficient to allow a car to park in a driveway without encroaching into the public right of way, and reduces driveway and walkway pavement by more than 30% compared with a setback of 30 feet (see **Figure 6.68** below). Reducing imperviousness also helps to reduce the urban heat island effect.

Further, reducing side yard setbacks and using narrower frontages can reduce total street length, especially important in cluster and open space designs. **Figure 6.69** below shows residential examples of reduced front and side yard setbacks and narrow frontages.

Flexible lot shapes and setback and frontage distances allow site designers to create attractive and unique lots that provide homeowners with enough space while allowing for the preservation of natural areas in a residential subdivision. **Figure 6.70** below illustrates various non-traditional lot designs. Market research and homeowner surveys have shown that, for the most part, flexible setbacks and frontage requirements can provide communities that are attractive to both homeowners and potential home buyers (ULI, 1992).

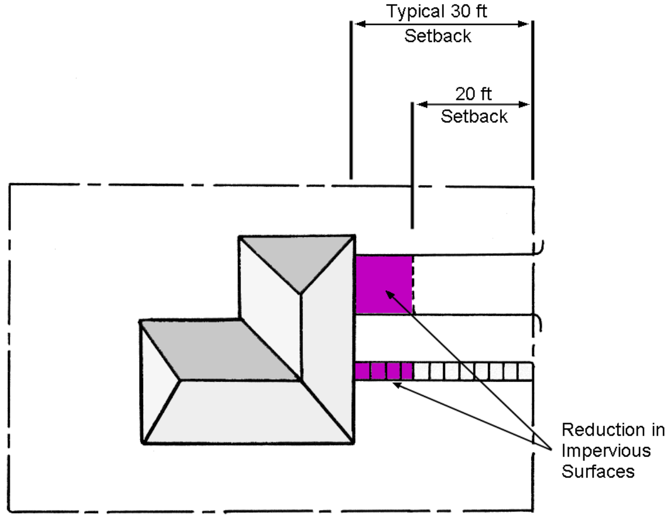
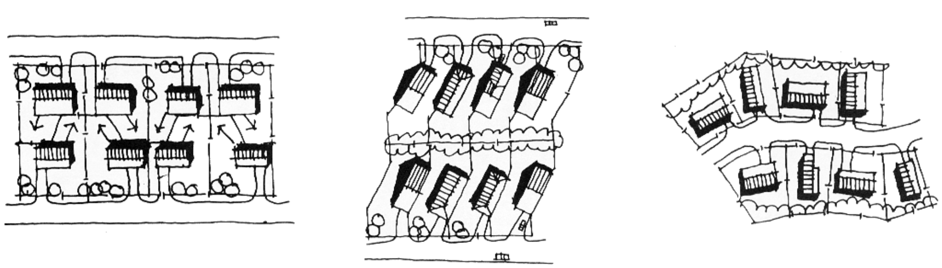


Figure 6.68. Reduced Impervious Cover by Using Smaller Setbacks
(Source: MPCA, 1989)

Figure 6.69. Examples of Reduced Frontages and Side Yard Setbacks
Source: ARC (2001)



Zipper Lots | Angled Z-Lots | Alternative Lot Widths

Figure 6.70. Non-Traditional Lot Designs
(Source: ULI, 1992)

Parking

One concern of this approach is that by reducing overall street length, reduced frontages result in less on-street parking. However, a frontage distance of fifty feet allows for on-street parking of two cars for each lot. Parking concerns can usually be addressed through site design in most residential zones.

A common parking concern relates to ownership of extra cars, boats, or large recreational vehicles. In the unlikely event that additional parking demand cannot be met through site design, communities may consider providing a common (shared) overflow parking area in the neighborhood (this is often done at apartment developments). When many homeowners are expected to own RVs or boats, expanding existing driveways using permeable pavement surfaces could provide the needed parking area.

Safety

Safety considerations include fire protection and adequate sight distances for drivers. Fire protection concerns focus on the proximity of structures to each other. When front and side setbacks are reduced, homes are closer together. This has led to the concern that fire could spread easily from one home to another. However, with the development of fire-retardant materials and the use of fire walls, the need for large setbacks has been reduced.

Adequate sight distance is an important aspect of safe road design. Site designers tend to rely on state and local government street criteria (e.g., minimum horizontal and vertical curve criteria) and rarely consider site (and lot) specific conditions when developing road layouts. According to AASHTO (1994), potential sight distance impairments can be avoided if visual obstructions (e.g., garages, front porches, etc.) are placed 1.5 feet or more from the curb. That small distance is considerably less than the 30-feet front setback required by many communities.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.12: Reduce urban heat island effects	3 - 5

6.5.3.5. Environmental Site Design Practice #15: Use Fewer or Alternative Cul-de-Sacs

KEY BENEFITS	USING THIS PRACTICE
• Reduces the amount of impervious cover and associated runoff and pollutants generated	• Consider alternative Cul-de-Sac designs
This practice reflects the CWP Better Site Design Principle #4 (Cul-de-Sacs)	

Cul-de-sacs are local access streets with a closed circular end that allows for vehicle turnarounds. Many of these cul-de-sacs can have a radius of more than 40 feet. From a stormwater perspective, cul-de-sacs create a huge bulb of impervious cover, increasing the amount of runoff. For this reason, reducing the size of cul-de-sacs through the use of alternative turnarounds or eliminating them altogether can reduce the amount of impervious cover created at a site.

Site designers should minimize the number of residential street cul-de-sacs and incorporate landscaped areas to reduce their impervious cover. The radius of a cul-de-sac should be the minimum required to accommodate emergency and maintenance vehicles. Alternative turnarounds should also be considered. Alternative turnarounds are designs for end-of-street vehicle turnarounds that replace cul-de-sacs and reduce the amount of impervious cover created in developments. Reducing imperviousness also helps to reduce the urban heat island effect.

Numerous alternatives create less impervious cover than the traditional 40-foot cul-de-sac. These alternatives include reducing cul-de-sacs to a 30-foot radius and creating hammerheads (“tees”), and loop roads (see **Figures 6.71**). Sufficient turnaround area is a significant factor to consider in the design of cul-de-sacs. In particular, the types of vehicles entering into the cul-de-sac should be considered. Fire trucks, service vehicles and school buses are often cited as needing large turning radii. However, some fire trucks are designed for smaller turning radii. In addition, many newer large service vehicles are designed with a tri-axle (requiring a smaller turning radius) and many school buses usually do not enter individual cul-de-sacs.

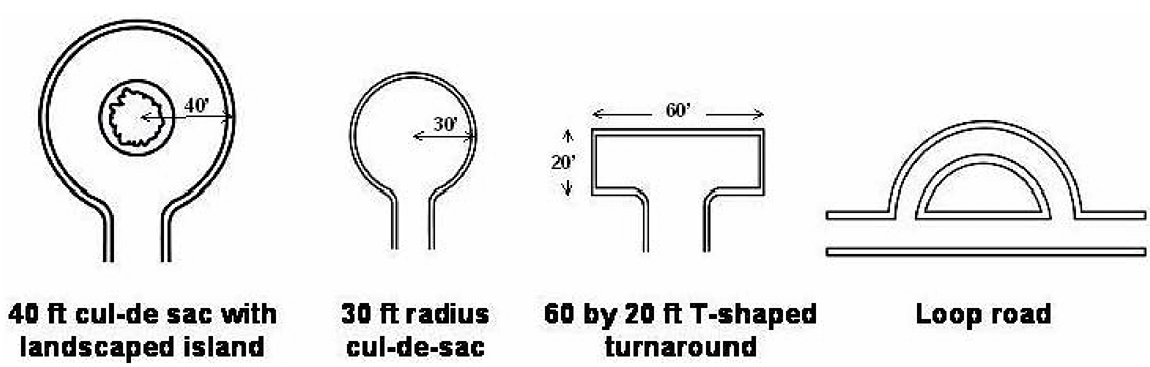


Figure 6.71. Four Turn-Around Options for Residential Streets
(Source: Schueler, 1995)

Another way to reduce the imperviousness of traditional cul-de-sacs is to creat a loop road, as shown in **Figure 6.72** below. Still another method is to create a pervious island or stormwater bioretention area in the middle of the cul-de-sac (**Figures 6.73 through 6.75** below).

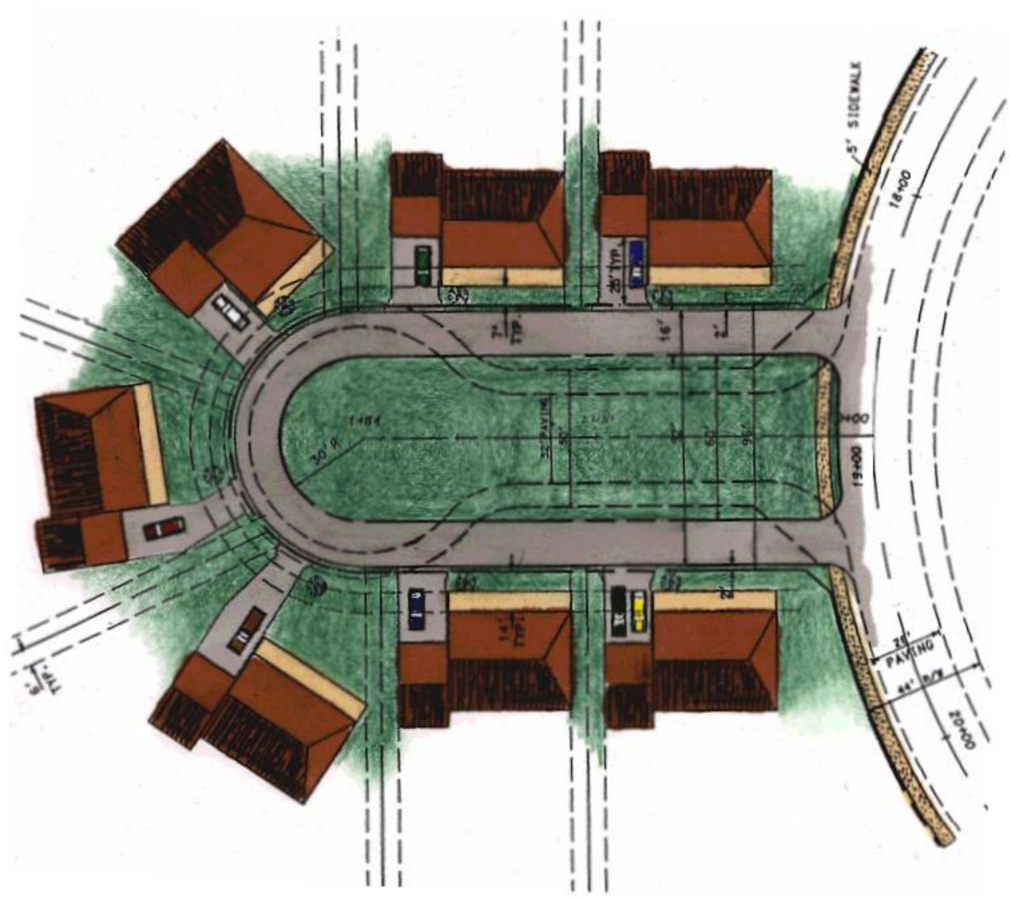


Figure 6.72. Use of a loop road to avoid creating a cul-de-sac.
Source: Chesapeake Bay Stormwater Training Partnership

Figure 6.73. Trees and vegetation planted in the landscaped Island of a cul-de-sac (left) and a loop road (right)
Source: MPCA (2006)

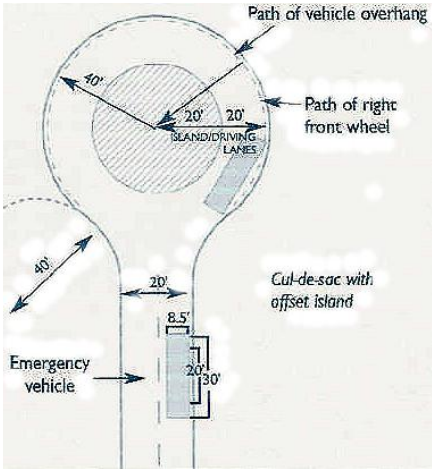


Figure 6.74. Alternative cul-de-sac design. Source: Connecticut Stormwater Quality Manual

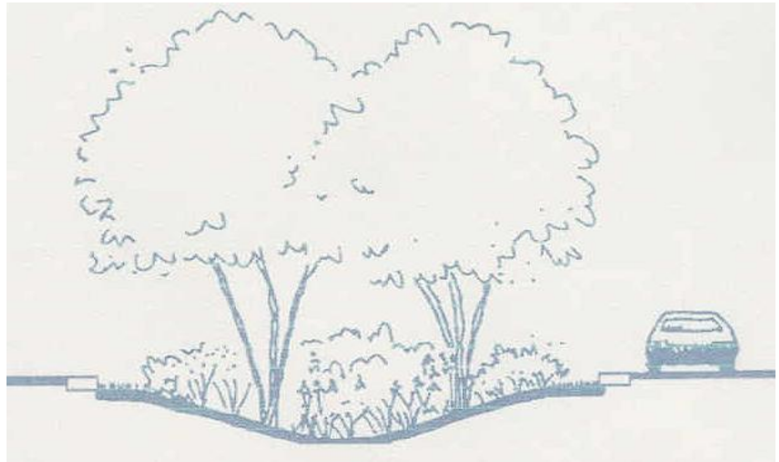


Figure 6.75. Recessed bioretention area in cul-de-sac Source: Connecticut Stormwater Quality Manual

Of course, another solution to the cul-de-sac problem is to apply site design strategies that avoid or minimize dead-end streets and cul-de-sacs altogether. Implementing alternative turnarounds will require addressing local regulations and marketing issues. Communities may have specific design criteria for cul-de-sacs and other alternative turnarounds that need to be modified.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
4.12: Reduce urban heat island effects	3 - 5

6.5.3.6. Environmental Site Design Practice #16: Create Parking Lot Stormwater "Islands"

KEY BENEFITS	USING THIS PRACTICE
• Reduces the amount of impervious cover and associated runoff and pollutants generated • Provides an opportunity for the siting of structural control facilities • Trees in parking lots provide shading for cars and are more visually appealing	• Integrate porous areas such as landscaped islands, swales, filter strips and bioretention areas in a parking lot design

Provide stormwater treatment for parking lot runoff using bioretention areas, filter strips, and/or other practices that can be integrated into required landscaping areas and traffic islands (**Figure 6.76**). Parking lots should be designed with landscaped stormwater management "islands" which reduce the overall impervious cover of the lot as well as provide for runoff treatment and control in stormwater facilities.

When possible, expanses of parking should be broken up with landscaped islands which include shade trees and shrubs. Fewer large islands will sustain healthy trees better than more numerous very small islands. The most effective solutions in designing for tree roots in parking lots use a long planting strip at least 8 feet wide, constructed with sub-surface drainage and compaction resistant soil.

Figure 6.76. Parking Lot Stormwater Island

Structural practices such as filter strips, dry swales and bioretention areas can be incorporated into parking lot islands. Runoff is directed into these landscaped areas and is temporarily detained. It then flows through or filters down through the bed of the facility and is infiltrated into the subsurface or collected for discharge into a stream or another stormwater facility. These facilities can be attractively integrated into landscaped areas and can be maintained by commercial landscaping firms. It is important to examine runoff volumes and velocities and ensure runoff enters bioretention facilities in a distributed manner and at non-erosive velocities. It is also important to ensure that bioretention facilities have proper pre-treatment. For detailed specifications of such practices, refer to the Virginia Stormwater BMP Clearinghouse website at: http://www.vwrrc.vt.edu/swc/ .

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9
4.12: Reduce urban heat island effects	3 - 5

6.5.4. Using Natural Features and Runoff Reduction to Manage Stormwater

An ESD strategy seeks to maximize the use of pervious areas at the site to help filter and infiltrate runoff generated from impervious areas and to spread excess runoff from these surfaces over pervious areas. Most development sites have extensive areas of grass or landscaping where runoff can be treated close to the source where it is generated. Designers should carefully look at the site for pervious areas that might be used to disconnect or distribute runoff.

Traditional stormwater drainage design tends to ignore and replace natural drainage patterns and often results in overly efficient hydraulic conveyance systems. Structural stormwater controls are costly and often can require high levels of maintenance for optimal operation. Through use of natural site features and drainage systems, careful site design can reduce the need and size of structural conveyance systems and controls.

Almost all sites contain natural features which can be used to help manage and mitigate runoff from development. Features on a development site might include natural drainage patterns, depressions, permeable soils, wetlands, floodplains, and undisturbed vegetated areas that can be used to reduce runoff, provide infiltration and stormwater filtering of pollutants and sediment, recycle nutrients, and maximize on-site storage of stormwater. Site design should seek to utilize the natural and/or nonstructural drainage system and improve the effectiveness of natural systems rather than to ignore or replace them. These natural systems typically require low or no maintenance and will continue to function many years into the future.

Soils are the foundation for successful planting, and the water holding capacity of soils can significantly reduce the volume of runoff from a site. In addition to successful plant growth, soils can be engineered to improve water holding capacity. For example, tight soils can be amended with compost to recover soil porosity lost due to the soil's natural materials, compaction as a result of past construction activities, soil disturbance, and on-going human traffic. The amendment process seeks to recover the porosity and bulk density of soils by incorporating soil (McDonald, 1999). The humus material of compost has a water holding capacity of up to 80 percent by weight. This quality is very significant when trying to decrease runoff and increase filtration.

On-site soils can be amended by incorporating compost into the soils or by laying a one to three inch "blanket" of compost on top of the soils. Fiber amendments can assist in maintaining soil structure even with heavy surface loads. The method chosen depends on site characteristics and the purpose it is intended to serve, such as promoting infiltration or reducing nutrient and sediment loading to surface waters. Some of the methods of incorporating natural features into an overall stormwater management site plan include the following practices:

- Manage stormwater outfalls to protect natural receiving waters
- Use buffers and undisturbed areas
- Use natural drainageways instead of storm sewers
- Use vegetated swales instead of curb and gutter
- Drain runoff to pervious areas
- Amend tight soils with compost

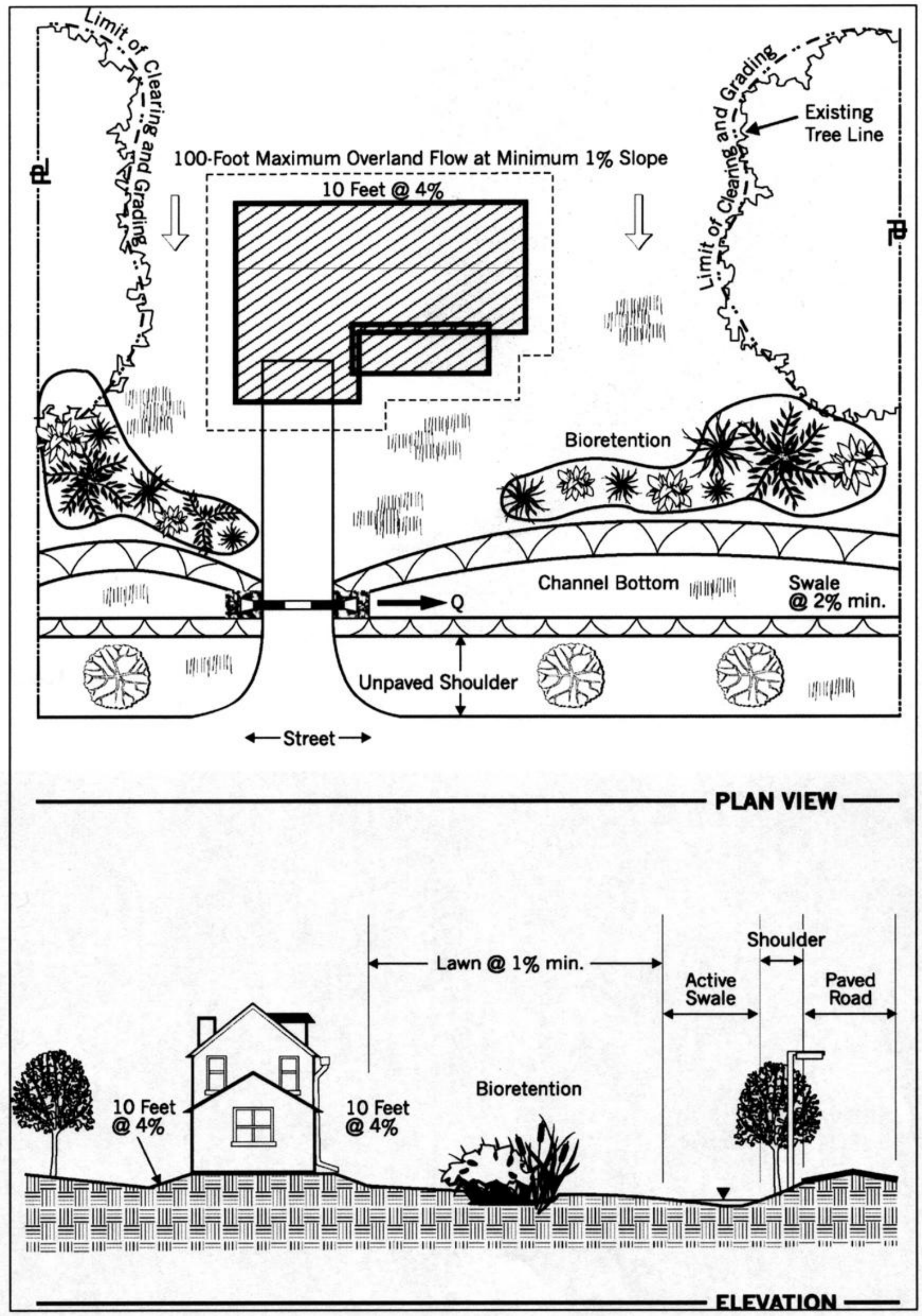


Figure 6.77. Residential Site Design Using Natural Features for Stormwater Management
(Source: Northern Shenandoah Valley Regional LID Manual, 2005)

The following pages cover each practice in more detail.

6.5.4.1. Environmental Site Design Practice #17: Use Buffers and Undisturbed Filter Areas

KEY BENEFITS	USING THIS PRACTICE
• Riparian buffers and undisturbed vegetated areas can be used to filter and infiltrate stormwater runoff • Natural depressions can provide inexpensive storage and detention of stormwater flows	• Direct runoff towards buffers and undisturbed areas using a level spreader to ensure sheet flow • Use natural depressions for runoff storage • Disconnect these areas from the flow from impervious areas

With proper design, undisturbed natural areas, such as forested conservation areas and riparian buffers, or vegetated filter strips, can be used to receive runoff in the form of sheet flow from upslope areas of the development site. Runoff can be directed towards grass filter strips, riparian buffers and other undisturbed natural areas delineated in the initial stages of site planning to infiltrate runoff, reduce runoff velocity and remove pollutants (see Stormwater Design Specification No. 2, Sheet Flow to Vegetated Filter Strip or Conserved Open Space). Natural depressions can be used to temporarily store (detain) and infiltrate water, particularly in areas with porous (hydrologic soil group A and B) soils. Vegetated filter strips may use existing vegetation or may be planted during the course of development.

The objective in utilizing natural areas for stormwater infiltration is to intercept runoff before it has become substantially concentrated and then distribute this flow evenly (as sheet flow) to the buffer or natural area. This can typically be accomplished using a level spreader, as seen in **Figure 6.78**. A mechanism for the bypass of higher flow events should be provided to reduce erosion or damage to a buffer or undisturbed natural area.

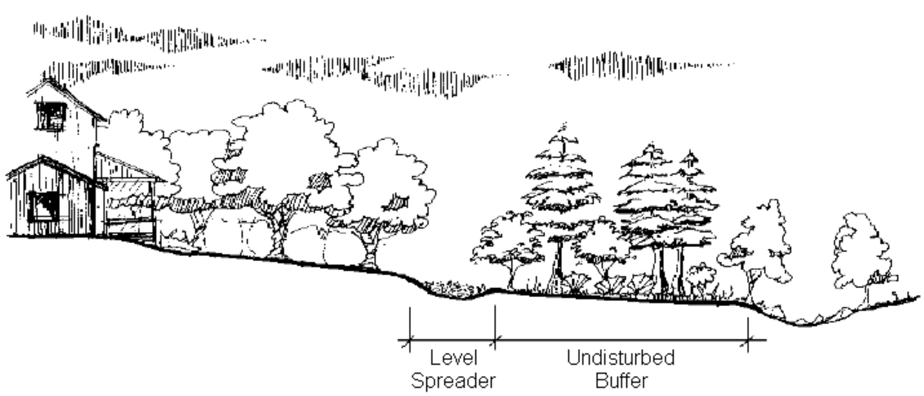


Figure 6.78. Using a Level Spreader with a Riparian Buffer
(Adapted from NCDENR, 1998)

Redirecting stormwater runoff from impervious surfaces to filter strips could also be categorized as "hydrologic disconnection" where the objective is to minimize stormwater conveyance through wide-scale distribution close to the point of generation. In these cases, sidewalks and driveways and other impervious features are designed to drain evenly onto adjacent pervious, presumably vegetated zones. Such zones may be lawn areas or planted groundcover, possibly even preexisting vegetation. In cases where contributing areas are relatively small in size and estimated flows are not great, provisions can be simple (e.g., roof drains discharging onto splash blocks). Carefully constructed berms can be placed around natural depressions and below undisturbed vegetated areas with porous soils to provide for additional runoff storage and/or infiltration of flows.

In the discussion here, Vegetated Filter Strips and Buffers are combined, although there are differences. One frequently cited difference is that filter strips often are created and planted, whereas buffers use existing vegetation. Another distinction is that filter strips ideally are located as close to the source of the runoff as possible, and are carefully integrated into the development landscape design (i.e., grassed filter strips often receive runoff from adjacent parking areas). In contrast, buffers are typically recommended as a technique to protect sensitive environmental features such as wetlands or stream corridors. Environmental site design includes proper buffering of these sensitive features from impact-generating uses.

Most filter strips have limited stormwater management capabilities and therefore, while still useful, are best suited for relatively low density development (i.e., flows generated by higher density development may be too intense). Also, their functions are maximized when only smaller storm events are treated (i.e., larger event flows should bypass the filter strip to prevent erosion). In many cases, filter strips are designed to treat up to the ½-inch rainfall, although both size of storm and density of development need to be taken into account. If designed properly, filter strips can be used to hold pre- to post-development runoff volumes constant. Practically speaking, this pre-to-post volume control is feasible only in relatively low density situations with the filter strip approach. Once runoff is concentrated and increases in rate and volume, the size of the required filter strip would need to be quite large – often impractically large – and provisions for managing the increased volume, such as use of berms, should be considered.

Another important aspect of quantity is peak rate control. Filter strips help to control peak rate as volume is controlled. As runoff passes through the filter strip and is infiltrated, peak rate is reduced. Although filter strips and buffers can infiltrate a certain amount of the runoff, they are often not adequate to satisfy peak rate criteria, especially when the contributing area is quite large. In these cases, they can be managed most effectively when used in conjunction with other ESD Practices and/or other stormwater control measures.

In terms of water quality, filter strips, when properly designed, are reasonably effective at reducing suspended solids and pollutants such as phosphorus that are bound to soil particles. The pollutants moving with infiltrated stormwater undergo physical, chemical, and biological removal processes. As stormwater moves through surface vegetation, resistance slows overland flow and promotes deposition of particulate pollutants (especially the larger particles). Pollutants are also removed through uptake by the vegetation itself. Plants absorb nutrients and even some metals. Over time, the sediment deposited, if not excessive, is incorporated into the soil mantle, aided by plant growth and decay. In low density applications and for small storm events, pollutant removal of non-soluble pollutants can be excellent. Specific design information and specifications on filter strips can be found on the Virginia Stormwater BMP Clearinghouse website at: http://www.vwrrc.vt.edu/swc/ .

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.3: Protect and restore riparian, wetland, and shoreline buffers	3 - 8
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9

6.5.4.2. Environmental Site Design Practice #18: Use Creative Site Grading, Berming and Terracing (Terraforming)

KEY BENEFITS	USING THIS PRACTICE
• Creative site grading can be used to temporarily slow, capture or direct runoff to areas for infiltration • Natural depressions can provide inexpensive storage and detention of stormwater flows	• Reserve or define and create specific zones for infiltration • Use creative grading to direct flow there • Location should not interfere with use of the site or integrity of structures • Do not compact permeable soils
This practice reflects the CWP Better Site Design Principle #19 (Clearing and Grading)	

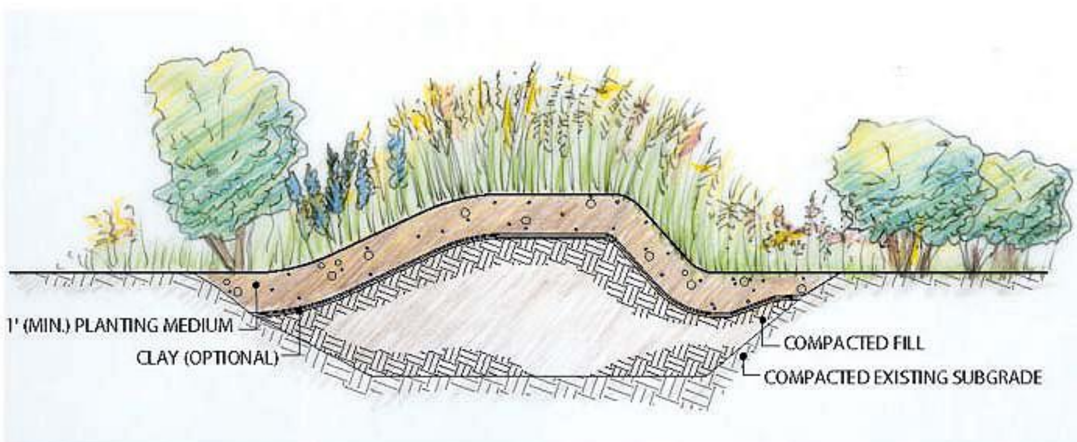


Figure 6.79. Components of a Berm Created for Stormwater Control
Source: Philadelphia Stormwater Manual

Many communities allow clearing and grading of an entire development site except for a few specially regulated areas such as jurisdictional wetlands, steep slopes, and floodplains. Very few communities restrict clearing and grading of buffers, open space and native vegetation during construction. As noted in the discussion of ESD Practice #1 (Preserve Undisturbed Natural Areas), sustainable design conserves as much of the site as is feasible in its natural state. Such conserved areas retain their natural hydrology and do not erode during construction. As a rule, clearing should be limited to the minimum area required for building and traffic footprints, construction access, and safety setbacks.

Terraforming is a term applied to a careful grading process designed to achieve specific objectives, such as infiltration rather than disposal of stormwater. Exact configurations resulting from this special grading may vary. For example, subtle, sometimes nearly imperceptible depressions or saucers can be integrated into the graded landscape to receive residential rooftop runoff or stormwater from the driveway or turnaround (see **Figures 6.80** below). Terraforming can be achieved at a micro-scale, replicated lot-by-lot, possibly replicating specific concepts throughout a development to facilitate both installation and ongoing maintenance (e.g., rear yard depressions, use of the driveway or elevated roadway to create subtle upslope dams, etc.).

Terraforming can be integrated effectively into larger scale site planning, such as at recreational areas or office parks, and can be independent of or integrated with BMPs such as bioretention or infiltration.

Figure 6.80. Berm Creates Small Bioretention Area.
Source: Philadelphia Stormwater Manual

A basic principle of environmental site design is to achieve an area-wide watershed build-out that minimizes total disturbance of natural vegetation and soil mantle to the extent possible. However, there are instances where the grading process can contribute to a positive solution, rather than resulting in environmental problems. Some communities have grading ordinances that prescribe maximum and minimum slopes for house lots. However, to maximize preservation of trees and other vegetation, some flexibility regarding slope criteria should be considered. For example, allowing a slightly steeper engineered slope in a limited area of the site than authorized by code may allow for preservation of more trees and native vegetation (see **Figure 6.81**).

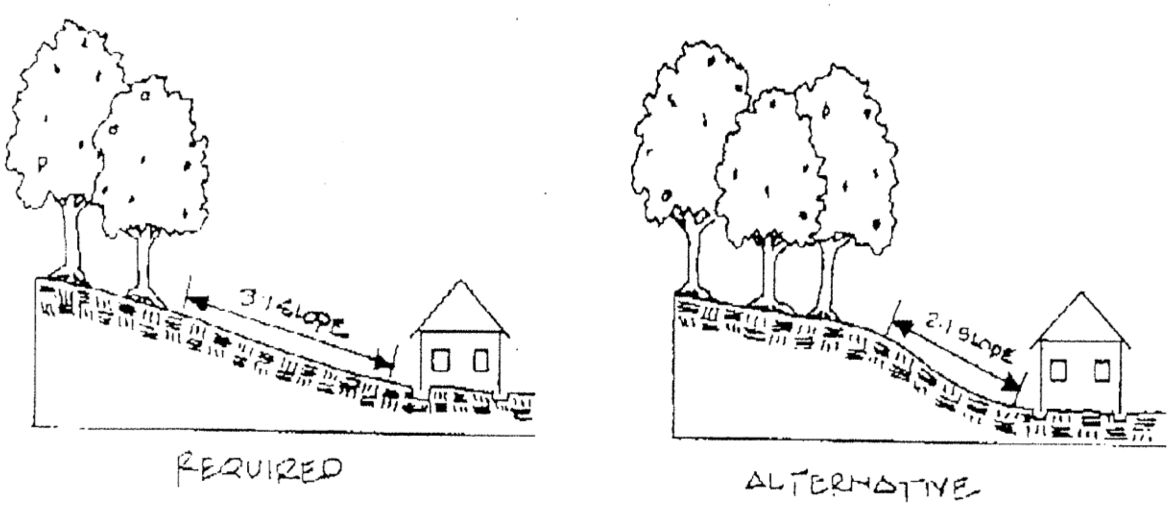


Figure 6.81. Allowing a Grading Variance Results in More Tree Protection
Source: CWP (1998a)

Disturbance of the natural vegetation and soil, if deemed necessary, can be accomplished carefully and with imagination so that natural processes can be exploited and enhanced to the maximum, and the full range of stormwater management objectives can be achieved. This particular technique, like so many others, is best used in conjunction with other techniques. Specific concepts range in scale and application from micro site-by-site terraformed saucers to creative use of subtle earthen berms placed in zones of existing vegetation.

In all cases, the objective is to achieve comprehensive stormwater management functions, including reduction of stormwater volumes, management of peak rates of discharge, and reduction of pollutant loadings. These objectives are accomplished as the runoff is collected and infiltrated through the soil mantle and the vegetative root zone, enabling a full range of physical, chemical, and biological processes to affect the stormwater.

However, because this technique is very reliant on the process of infiltration, all the factors constraining the use of infiltration-oriented BMPs come into play. Soil characteristics are critical. Tight soils with extremely poor permeability will suffer even worse compaction if graded and regraded, so they should not be considered for terraforming. Depth to bedrock and the seasonal high water table must be considered. Of course, berming in areas with existing vegetation and a developed root zone can be expected to provide better soil permeability.

Creative terraforming may not work in all developments. To the extent that concentrated development configurations are used, any lot-by-lot approach might be difficult to implement. Even in such settings there may be opportunities to use terraforming elsewhere on the site, such as in recreational open spaces. However, for those developments that have large lots with ample space for onsite stormwater management, the feasibility of terraforming should be considered.

Basic Criteria

Basic criteria or principles must be respected. In extremely heavy clayey soils, soil compaction may prevent infiltration. As with any infiltration-driven concept, avoid zones near structures, septic system drainfields, and so forth. Setback distances should vary with topography and other factors (e.g., infiltration downslope of basements requires less separation distance than infiltration upslope of basements). Furthermore, location of any terraformed areas should be evaluated from a user perspective. Ideally, the location should not interfere with but rather should enhance use of the site, such as sports playing fields. Usually this is not difficult to accomplish.

To the extent that this micro-scale site-by-site or grouped-site approach can be implemented, the terraforming concept is quite similar to designing for onsite septic system drainfields. The objective is to define and reserve specific areas of the site to accommodate these natural functions, whether the need be wastewater effluent management or stormwater management.

Berms

Berms are landscape features located along existing contours in moderately sloping areas. They are usually designed to intercept and direct runoff or to promote stormwater detention and infiltration. Berms and shallow depressions are suitable terraforming tools for both small and large projects. In most cases, berming is most effective when used in conjunction with other environmental site design principles and practices discussed in this chapter:

- A berm and depression can act as pre-treatment (e.g., a sediment forebay) before stormwater enters a a BMP such as a bioretention basin or infiltration facility.
- A berm placed downslope of such facilities can increase their detention capacity without additional excavation.
- A shallow depression can be created behind a berm to provide an small detention or infiltration area without the need for a more complex stormwater control measure.
- A berm can be placed across a slope to divert water to a nearby channel or BMP.
- A series of small berms and depressions can be placed along a slope to provide infiltration and detention while stabilizing the slope (see **Figure 6.82** below). However, as the slope increases, berms become more challenging to construct and the extent of natural area disruption increases.

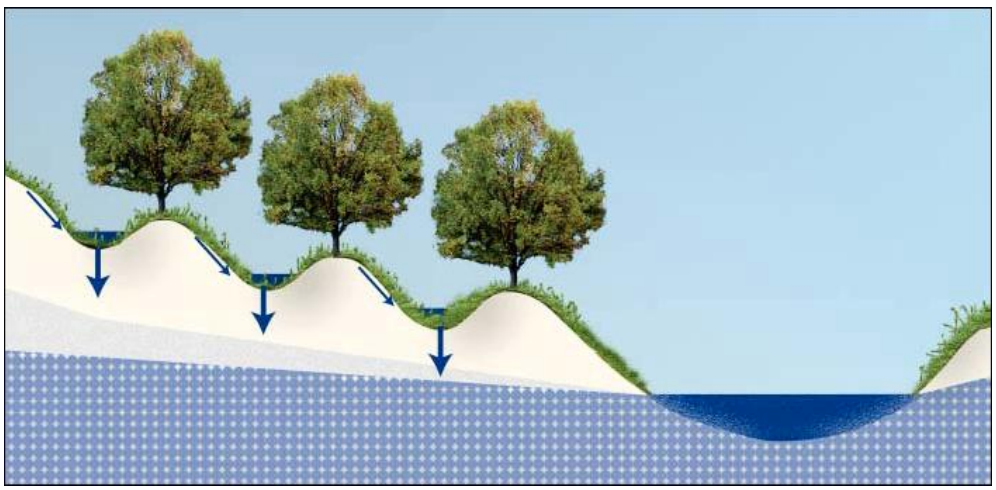


Figure 6.82. Successive Berms on Slope Create Multiple Bioretention Areas.
Source: Philadelphia Stormwater Manual

Conceptually, the fundamental work of the berm is to block the passage of runoff, retain it, and allow it to infiltrate naturally into vegetated areas upslope. In the ideal, a berm would simply be an impermeable wall, the top of which would assure sheet flow from larger storms onto vegetated areas downslope. It is critical that areas upslope be able to infiltrate stormwater and that areas downslope be able to handle overflow.

Although stormwater can be piped and conveyed down to the berm itself, the best use of berms includes level-spreading of runoff well upslope, allowing for sheet flow down to the berm itself.

This approach maximizes opportunity for recharge prior to the berm and minimizes the volume or runoff that must be retained and infiltrated thereafter.

When flooding is likely to occur (i.e., within a flood plain), a system of mounds or berms can be created to reduce the velocity of flood waters, creating a more gradual flooding process. If berms are placed correctly (see **Figure 6.83**), they can divert peak flows away from structures and trap sediments before runoff carries them into the stream. **Figure 6.84** illustrates several creative ways in which earth mounds may be incorporated into playground configurations as significant play features as well as flood diversions. Of course, flood routing must be performed to assure that creation of berms or mounds in the flood plain will not result in an increase of the flood elevation at downstream sites.

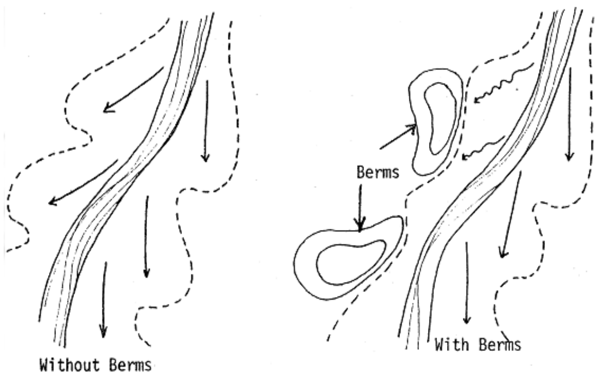


Figure 6.83. Berms Controlling Flood Flows
Source: Day and Crafton (1978)

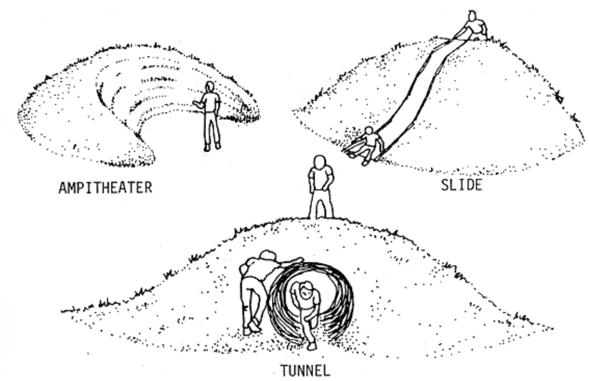


Figure 6.84. Creative Berm Configurations
Source: Day and Crafton (1978)

Berming includes both residential and nonresidential applications, ranging from individual lots to broader site-wide installations. Berms can be incorporated with individual driveways, lot-by-lot, in order to direct and infiltrate runoff from roads and driveways. Such berm systems may intersect a vegetated swale, with the berms extending along the contours into the respective lot and providing volume control as needed.

Berming can be carefully integrated into total site development by taking advantage of areas of existing vegetation. Larger volumes of stormwater can be directed to these natural areas, where volume control can be provided through placement of a berm. Depending upon the configuration of the development, some sort of level spreading device may be necessary to properly distribute the larger flows to the natural area. It is important to note that slope is a key determinant of whether this approach can be used. If large areas of relatively flat land with existing vegetation (ranging from dense forest to scrub growth) are available to receive stormwater runoff, then such an approach is ideal and can be accomplished with minimal difficulty. If the stormwater initially is evenly spread upslope of the area, sheet flow will be generated. Sheet flow not infiltrated from the larger storms will be detained by the berm. Once contained, this stormwater will be infiltrated, aided and abetted by the enhanced permeability of the vegetated floor of the natural area.

Berms may be designed to detain and contain storms of any size (see **Figure 6.85**). If the size of the bermed area is sufficient to detain the difference between pre-development and post-development flow for up to the 2-year storm (a reasonable recharge target), then larger storms will have to bypass the berm. In such cases, the berm itself becomes a level spreading device, and reinforcement of the berm may be necessary for structural stability. Here, the berm top and sides can be reinforced through use of "geowebs" or "geogrids" which significantly increase stability if significant erosive forces must be withstood. Of course, reinforcement increases the cost. Reinforcement may be also necessary when flows are substantial and slopes are considerable.

Figure 6.85. Berms Form a Basin to Detain Runoff from Larger Storms

Berm Design

Berms should be designed within the context of stormwater quality, channel protection, and flood protection requirements applicable to the site and as part of the stormwater management system for the site.

- Create a conceptual stormwater management plan for the entire site, and determine what portion of the sizing requirements berms and retentive grading will help to meet. Determine the general location of these features and the role they will play on the site. The ideal berm location is on moderately rolling terrain, rather than more severe slopes, where channelization upslope of the berm is not necessary in order to achieve storage volumes and where natural vegetation remains undisturbed up to the base of the berm.
- Placement of the berm must be accomplished carefully. The objective is to avoid significant disruption of the natural area, whether in mature forest, dense scrub growth, or meadow. Berm dimensions have an important bearing on the extent of disruption created. The berm

must be stable, but at the same time it should be no taller and no longer in base area than is absolutely necessary for stability. Only the minimum volume of fill material should be used for the berm.

- Create a conceptual design for the berm(s), including height of the berm and depth of the depression. Suggested starting design values for berms are 6-24 inches for berm height and 6-12 inches for ponding depth behind the berm. If more volume is needed that can be provided behind a 24-inch high berm, additional berms should be considered. The width of the top of the berm and the thickness of the berm itself should be a function of slope and stormwater volume to be handled. This must be evaluated on a case-by-case basis in order to guarantee structural stability.
- Berm slopes should not exceed a 3:1 (H:V) ratio. If the berm is to be mowed, the slope should not exceed a 4:1 ration in order to avoid "scalping" by the mower blade. If trees are to be planted on the berm, the slope should not exceed a ratio ranging from 5:1 to 7:1. The top of the berm should be level so as prevent concentrating (at lower spots) any overflow during larger storms.
- If the berm will be linked with a depression intended to promote infiltration, an soil infiltration test should be performed. If infiltration is feasible, determine the engineer's best estimate of saturated vertical infiltration rate, with an appropriate factor of safety. These test results should be included with site plans provided to the local plan review authority for approval.
- Estimate the amount of runoff reaching the system during the design storm and the maximum ponding depth or elevation at the berm. The design infiltration rate may be subtracted from stage at each time step in this calculation.
- Using the infiltration area and the saturated vertical infiltration rate of the native soil, estimate how long the surface ponding will take to drain. The maximum drawdown time for the entire storage volume should not exceed 72 hours; a drawdown period of 24-48 hours is recommended, based on site conditions and owner preference. If routings indicate the stored water will not drain in the time allowed, adjust the berm height and depression depth until the time constraints are met. These routings should be included with the site plans provided to the local plan review authority for approval.
- Design an overflow or bypass mechanism for large storms, accounting for appropriate erosion protection. The contours of the site may allow water to flow around the edge of the berm, provided that erosion will not occur or sufficient protection is provided.
- To minimize cost, check the volume of cut and fill material and adjust the berm height and depression depth to more closely balance the two.
- Consider maintenance activities when choosing berm materials and shape (see **Figure 6.79** on page 108 above).

Berm Construction

Berm construction should first include channel excavation parallel to contours and then mounding of excavated material into berm formation at the lower edge of the channel (**Figure 6.86** below. Upslope of the berm itself, a broad flat cleared area is created. This approach readily provides a storage volume. If excavation volume and berm fill balances, this approach is quick and easy. However, excavation for channelization should be avoided, in order to minimize disruption and compaction of soils in the areas upslope of the berm where infiltration is so critical.

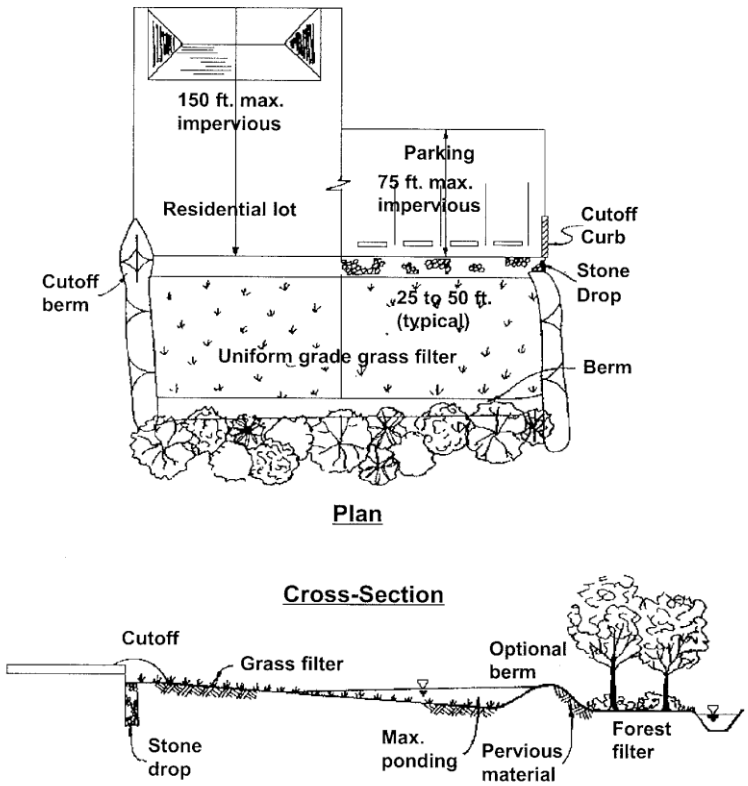


Figure 6.86. Example of a Filter Strip with "Terraforming" Berming

The following is additional guidance on the construction of berms:

- It is very important that areas where infiltration berms will be established must be clearly marked before any site work begins, to avoid soil disturbance and compaction during construction. Also, construction runoff must be directed away from the proposed infiltration berm location. Berm excavation and construction should not be done until other site grading is complete and the drainage area has been fully stabilized.
- Existing soil surfaces of any proposed infiltration area should be manually scarified, so the in-situ soils will not be compacted. Heavy equipment must not be used in the berm area.
- Topsoil should be stripped and stockpiled carefully and saved for replacement, using a small loader. It is important that organic material be stripped down to a solid mineral base in order to make sure that the interface between the berm fill material and the parent soil is tight.
- The excavated area should be backfilled as soon as the subgrade preparation is complete to avoid accumulation of debris. Place the berm granular fill, free of organic matter. Use appropriate construction equipment so as to prevent disturbance and compaction of up-slope areas as well as down-slope areas (protection up-slope areas is most critical). The berm should be created in 8-inch lifts, tamped lightly. The berm should be graded as fill is added and compacted consistent with applicable standards for fill material. Topsoil should be replaced following berm compaction.

- The surface ponding area at the base of the berm should be protected from compaction. If compaction occurs, the soil should be scarified to a depth of at least 8 inches.
- After allowing for settlement, final grading should be completed to within 2 inches of the proposed design elevations. The crest and base of the berm should be level along the contour.
- The top and downslope side should be stabilized with a non-erosive covering (e.g., erosion control netting or matting, etc.). When the side slopes are steeper than 5:1 (H:V), then the lip of the berm should be stabilized with a light-duty geoweb-type product. Then the surface should be seeded and planted with vegetation specified in the project plans and specifications. It is critical that the plant materials are appropriate for the soil, hydrologic, light and other site conditions. Native trees, shrubs and grasses are strongly recommended, but turf grass is acceptable. Although the plants will be subject to ponding, they may also be subject to drought, especially in areas that get a lot of sunlight or are in otherwise highly impervious areas.
- Mulch should be placed to prevent erosion and protect the new vegetation, manually grading the berm to its final elevations. Ideally, the area should be watered at the end of each day for two weeks following the completion of planting.

Berm Maintenance

- Periodically remove trash, debris and invasive plants from the area.
- If turfgrass is present, mow the grass to maintain a 2-4 inch height.
- Inspect periodically for erosion, and repair and stabilize eroded areas.

Economics of Terraforming

The economic benefits associated with minimizing clearing and grading and use of terraforming are two-fold. First, designing in sync with the terrain minimizes earthwork costs, often by thousands of dollars per acre. Second, through minimizing clearing, the volume of stormwater runoff generated on the site is reduced, resulting in lower stormwater management costs. As has been mentioned elsewhere, the cost of maintaining forests and open space is minimal compared to maintaining impervious surfaces and managed turf.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9
4.8: Preserve plant communities native to the ecoregion	2 - 6
4.9: Restore plant communities native to the ecoregion	1 - 5
4.13: Reduce the risk of catastrophic wildfire	3

6.3.5.3. Environmental Site Design Practice #19: Use Natural Drainageways and Vegetated Swales Instead of Storm Sewers and Curb & Gutter

KEY BENEFITS	USING THIS PRACTICE
• Use of natural drainageways reduces the cost of constructing storm sewers or other conveyances, such as roadway curbs and gutters, and may reduce the need for land disturbance and grading • Natural drainage paths are less hydraulically efficient than man-made conveyances, resulting in longer travel times and lower peak discharges • Can be combined with buffer systems to allow for stormwater filtration and infiltration • Reduces the cost of road and storm sewer construction	• Preserve natural flow paths in the site design • Direct runoff to natural drainageways, ensuring that peak flows and velocities will not cause channel erosion • Use vegetated open channels (enhanced wet or dry swales or grass channels) in place of curb and gutter to convey and treat stormwater runoff
This practice reflects the CWP Better Site Design Principle # 5 (Vegetated Open Channels)	

Figure 6.87. Dry swale along a suburban connector street (no curb and gutter).
Source: Chesapeake Bay Stormwater Training Partnership

Where density, topography, soils and slopes permit, the natural drainageways of a site, or properly designed and constructed vegetated channels and swales, should be used to convey and treat stormwater runoff instead of constructing underground storm sewers, concrete open channels, or roadway curb and gutter structures. Streets, in particular, contribute higher loads of pollutants to urban stormwater than any other source in residential developments (Bannerman, et al., 1993 and Steuer, et al., 1997). Research has indicated that residential streets contribute a majority of the sediment, phosphorus, copper, zinc, and fecal coliform bacteria found in urban stormwater runoff. Some examples of these pollutant sources (see **Figure 6.88**) are as follows:

- Atmospheric pollutants settle or are washed onto the street during rain events
- Pavement fragments contribute to stormwater pollution
- Vehicles contribute emissions and tire and brake system particles and residues
- Snow collected at the street edge melts and contributes salts
- Leaves and pollen from trees are blown into the street
- Curb and gutter systems channel polluted stormwater directly into streams

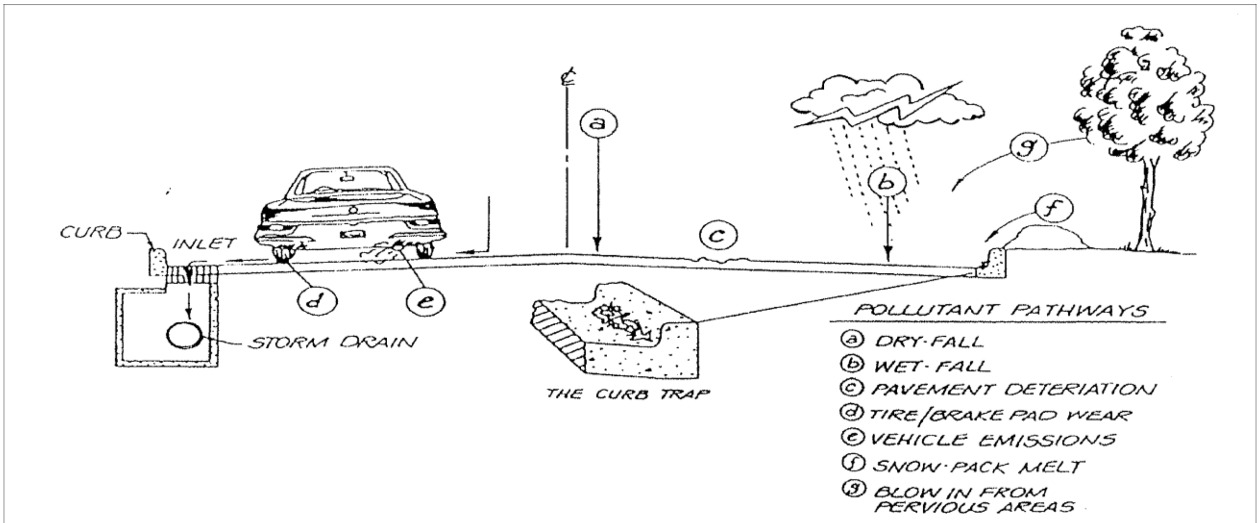


Figure 6.88. Street-Related Runoff Pollutant Pathways
Source: Schueler (1995)

Structural drainage systems and storm sewers are designed to be hydraulically efficient in removing stormwater from a site. However, these systems also tend to increase peak runoff discharges, flow velocities and the delivery of pollutants to downstream waters. A preferred alternative is the use of natural drainageways and vegetated swales (where slopes and soils permit) to carry stormwater flows to their natural outlets, particularly for low-density development and residential subdivisions. It is critical that natural drainageways be protected from higher post-development flows by ensuring that runoff volumes and velocities provide adequate residence times and non-erosive conditions and, as needed, by applying downstream channel protection methods (e.g., check dams and channel or outlet armor).

The conventional structural conveyance system in most cases provides no water quality management function and returns no stormwater back into the ground. Velocities and erosive forces of stormwater are actually worsened by such systems. Although vegetated swales vary in their intended objectives and design, the overall concept of a vegetated swale is to slow stormwater flows, capture some proportion of stormwater pollutants through biofiltration or bioretention, and hopefully infiltrate some portion of flow back into the ground.

Swales can act in two ways to affect stormwater flows. First, simple conveyance in a vegetated channel causes a decrease in the velocity of the flow. As the water passes over and through the vegetation, it encounters resistance. This resistance translates into increased times of concentration (slowing the flow) within the watershed, more temporary storage of stormwater on-site during the storm, and reduced peak discharge rates. The result can be a reduction in habitat destruction and streambank erosion that often is caused by peak flows of small storms, which comprise a majority of the rainfall events. Some of the flow will also infiltrate, depending on the design of the swale and the residence time.

Secondly, water quality can be affected by passage through vegetation. All the physical, chemical, and biological processes previously described can significantly reduce the pollutant loadings in stormwater. For example, total suspended solids are often reduced by settling, as a result of decreased flow velocity. Vegetation can also directly absorb nutrients and utilize them in growth.

Vegetated channels can be designed to meet a broad array of stormwater management objectives and to accommodate a variety of site specific situations. They are commonly used in single family residential areas with low to moderate impervious cover in place of curb and gutter systems as part of a drainage easement. They are also often used along roadsides, in the medians of highways, or in recessed areas of parking lots.

Where density, topography, soils, slope, and safety issues permit, vegetated open channels can be used in the street right-of-way to convey and treat stormwater runoff from roadways. Curb and gutter and storm drain systems allow for the quick transport of stormwater, which results in increased peak flow and flood volumes and reduced runoff infiltration. Curb and gutter systems also do not provide treatment of stormwater that is often polluted from vehicle emissions, pet waste, lawn runoff and litter.

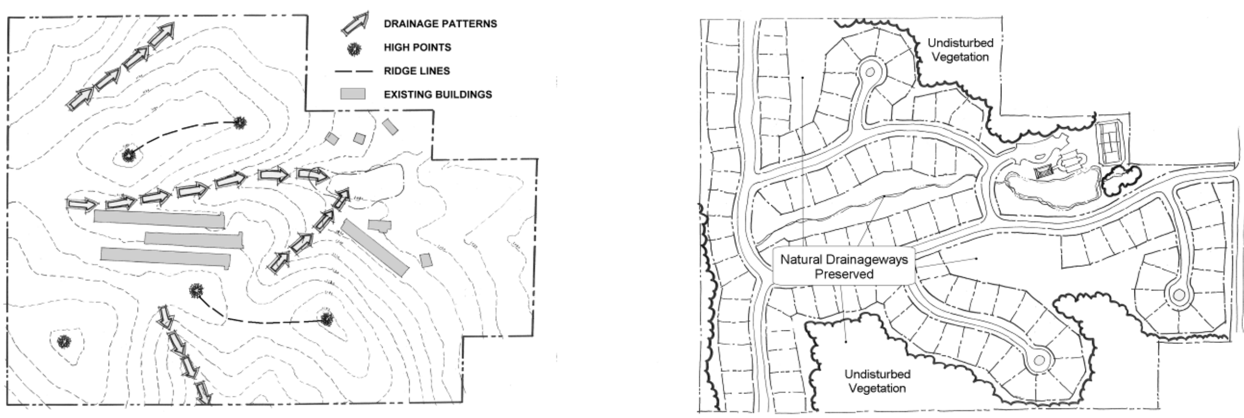


Figure 6.89. Example of a Subdivision Using Natural Drainageways to Treat and Convey Stormwater
Source: ARC (2001)

Open vegetated channels along a roadway (see **Figures 6.90** through **6.92** below) remove pollutants by allowing infiltration and filtering to occur, unlike curb and gutter systems which move water with virtually no treatment. Engineering techniques have advanced the roadside ditches of the past, which suffered from erosion, standing water and break up of the road edge. Grass channels and enhanced dry swales are two such alternatives and with proper installation under the right site conditions, they are excellent methods for treating stormwater on-site. In addition, open vegetated channels can be less expensive to install than curb and gutter systems. Further design information and specifications for grass channels and enhanced swales can be found on the Virginia Stormwater BMP Clearinghouse website at: http://www.vwrrc.vt.edu/swc/ .

Figure 6.90. Using Vegetated Swales Instead of Curb and Gutter
Source: ARC (2001)

Figure 6.91. Grass Channel in Median.
Source: Center for Watershed Protection

Figure 6.92. Subdivision Street Swale Drain.
Source: Center for Watershed Protection

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9

6.5.4.4. Environmental Site Design Practice #20: Drain Runoff to Pervious Areas

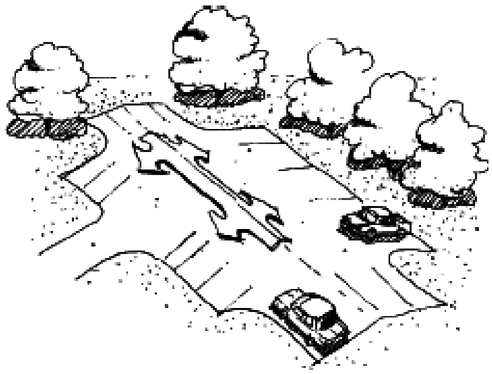
KEY BENEFITS	USING THIS PRACTICE
• Harvesting rooftop runoff keeps the water on-site for reuse and reduces domestic water and sewer costs • Sending runoff to pervious vegetated areas increases overland flow time and reduces peak flows • Vegetated areas can often filter and infiltrate stormwater runoff	• Minimize directly connected impervious areas and drain runoff as sheet flow to cisterns or pervious vegetated areas
This practice reflects the CWP Better Site Design Principle # 16 (Rooftop Runoff)	

Where possible, direct runoff from impervious areas (e.g., rooftops, roadways and parking lots) to cisterns for on-site reuse or to pervious areas such as yards, open channels or vegetated areas to provide for water quality treatment and infiltration. Avoid routing runoff directly to the roadway or structural stormwater conveyance system. Sending runoff over a pervious surface before it reaches an impervious surface can decrease the annual runoff volume from residential development sites by as much as 50 percent (Pitt, 1987). This grading and design technique can significantly reduce the annual pollutant load as well.

Stormwater quantity and quality benefits can be achieved by routing the runoff from impervious areas to pervious areas such as lawns, landscaping, filter strips and vegetated channels. Much like the use of undisturbed buffers and natural areas (Environmental Site Design Practice #17), revegetated areas such as lawns, engineered filter strips and vegetated channels can act as biofilters for stormwater runoff and provide for infiltration in porous soils (hydrologic group A and B). In this way, the runoff is "disconnected" from a hydraulically efficient structural conveyance such as a curb and gutter or storm drain system. Some of the methods for disconnecting impervious areas include:

- Designing roof drains to flow to infiltration trenches or vegetated areas
- Directing flow from paved areas such as driveways to stabilized vegetated areas (see **Figure 6.93** below)
- Breaking up flow directions from large paved surfaces
- Carefully locating impervious areas and grading landscaped areas to achieve sheet flow runoff to the vegetated pervious areas

For maximum benefit, runoff from impervious areas to vegetated areas must occur as sheet flow and vegetation must be stabilized. Specific design information and specifications for rainwater harvesting, sheet flow to vegetated filter strips and open space, and grass channels, dry swales, bioretention, and infiltration can be found on the Virginia Stormwater BMP Clearinghouse website at: http://www.vwrrc.vt.edu/swc/ .



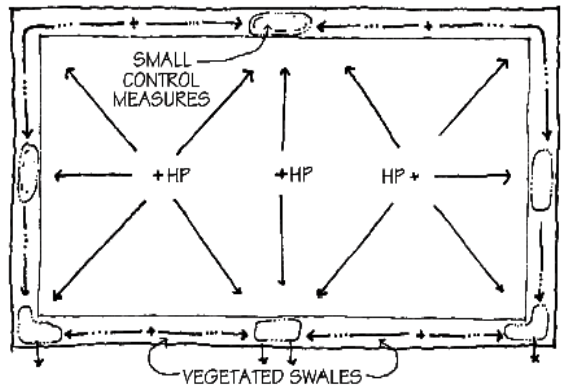


Figure 6.93. Using Vegetated Swales Instead of Curb and Gutter
Source: NC DENR (1998)

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9

6.5.4.5. Environmental Site Design Practice #21: Infiltrate Site Runoff or Capture It for Reuse

KEY BENEFITS	USING THIS PRACTICE
• Helps to preserve the natural hydrology of a site • Helps to recharge groundwater and thus maintain the baseflow of local streams • Removes pollutants that would otherwise be exported from the site • Lower runoff volumes leaving the site protects receiving waters from degradation • Capturing and/or reducing runoff volume on-site can reduce the amount and cost of drainage infrastructure for the site • Reusing captured runoff on-site (e.g., irrigating landscaping) can reduce owner costs for potable water	• Direct rooftop runoff to pervious areas such as yards, open channels, vegetated areas or infiltration practices or capture it in rain tanks or cisterns for reuse • May be used for roadway or parking impervious areas if adequate pre-treatment is provided • Use permeable pavement only in low traffic areas or for pedestrian walkways/plazas

Direct runoff from rooftop areas to pervious areas or use "vegetated roof" strategies to reduce rooftop runoff volumes and rates. Use infiltration trenches, basins, or leaching chambers to provide groundwater recharge, mimic existing hydrologic conditions, and reduce runoff and pollutant export. Permeable paving surfaces may also be used where site conditions are appropriate.

Capturing rainwater and rooftop runoff on-site provides an opportunity to not only reduce runoff volume discharging from the site, but also to use the water on-site, reducing the amount of potable water required for routine use. For example, roof downspouts discharging to rain tanks (**Figure 6.94**) can store water to be used for irrigating landscaped borders, washing vehicles, etc. Sophisticated capture systems can even be connected to the building's plumbing for use in flushing toilets, bathing, etc. While not as adaptable to older buildings, such systems incorporated into new construction can achieve payback in just a few years. Vegetated roofs (**Figure 6.95**) actually store the water in the vegetation's growing media, providing moisture to the plant materials that would otherwise need to be provided from potable sources.

Figure 6.94. Rain Barrel

Figure 6.95. Vegetated Roof

Surface disconnection spreads runoff from small parking lots, courtyards, driveways and sidewalks into adjacent pervious areas at the site where it is filtered and infiltrated into the soil. Most development sites have extensive areas of grass or landscaping where runoff can be treated close to the source where it is generated. In some cases, minor grading of the site may be needed to promote overland flow and vegetative filtering. Using infiltration trenches (**Figure 6.96**) and basins to filter runoff back into the ground helps to reduce the amount of stormwater runoff volume and associated pollutants that would otherwise be discharged from the development site. Rooftop runoff may be discharged directly to dry wells or infiltration chambers (**Figure 6.97**) or into perforated pipes spreading underground to provide moisture for a lawn (**Figure 6.98**).

Figure 6.96. Infiltration Trench

Figure 6.97. Dry Well

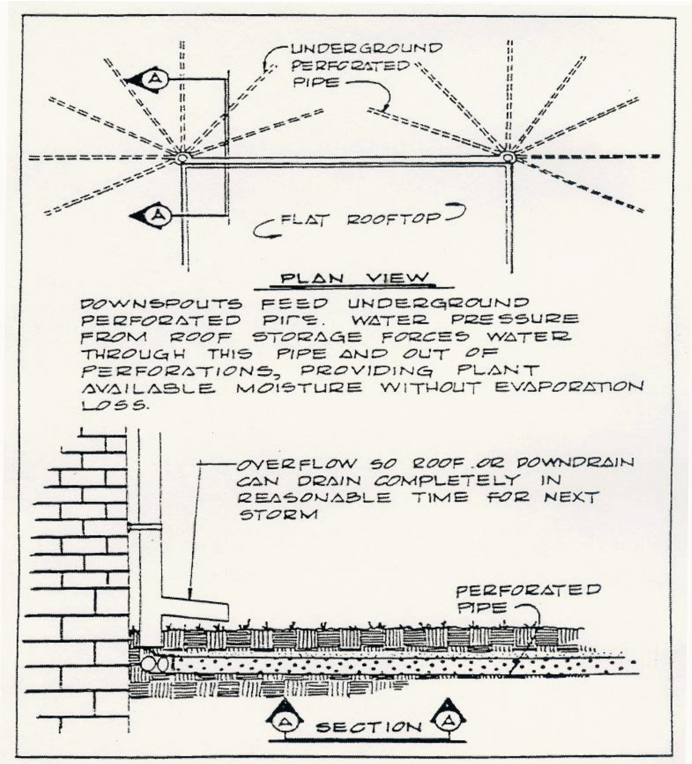


Figure 6.98. Downspout Connected to Infiltration Trenches Spread Out to Provide Underground Moisture to Lawn. Source: Baltimore SWM Manual

Porous paving materials should be used only in low traffic areas or for pedestrian walkways, plazas, and outdoor playing surfaces (e.g., basketball and tennis courts) (**Figures 6.99** and **6.100**)

In order to employ infiltration practices, the site must have soils with moderate to high infiltration capacities and must have adequate depth to groundwater and underlying geology. Poor soils will inhibit or even preclude aggressive infiltration. However, site soils can be amended with compost and other appropriate materials to improve the infiltration capacity. Care must be taken to avoid infiltrating runoff from stormwater hotspots unless adequate pre-treatment is provided. Infiltration on sites developed in karst areas should be limited to micro- and small-scale infiltration practices. Large-scale infiltration practices will likely increase the risk of sinkhole formation.

Figure 6.99. Porous Asphalt Bike Path

Figure 6.100. Porous Asphalt Playing Court

For more specific information about using rainwater harvesting, vegetated roofs, infiltration devices, soil amendments, or permeable paving surfaces see the Specifications for these practices on the Virginia Stormwater BMP Clearinghouse web site at: http://www.vwrrc.vt.edu/swc/ .

Traditionally, landscaping and stormwater management have been treated separately in site planning. In recent years, engineers and landscape architects have discovered that integrating stormwater into landscaping features can improve the function and quality of both. The basic concept is to adjust the planting area to accept stormwater runoff from adjacent impervious areas and utilize plant species adapted to the modified runoff regime (**Table 6.20**). Excellent guidance on how to match plant species to stormwater conditions can be found in Cappiella et al. (2005).

Table 6.20. Environmental Factors to Consider When Integrating Stormwater and Landscaping

Factor	Problem Addressed
Duration and depth of inundation	Invasive plants
Frequency of inundation	Pollutants and toxins
Available moisture during dry weather	Soil compaction
Sediment loading	Susceptibility to erosion
Salt exposure	Browsers (deer and beavers)
Nutrient loading	Slope

Source: Adapted from Shaw and Schmidt (2003)

A landscaping area may provide full or partial stormwater treatment, depending on site conditions. An excellent example of the use of landscaping for full stormwater treatment is bioretention. Even small areas of impervious cover should be directed into landscaping areas since stormwater or melt water help to reduce irrigation needs.

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.1: Reduce potable water use for landscape irrigation by 50 percent from the established baseline	0 (Prerequisite)
3.2: Reduce potable water use for landscape irrigation by 75 percent from the established baseline	2 - 5
3.5: Manage stormwater on the site	5 - 10
3.6: Protect and enhance on-site water resources and receiving water quality	3 - 9

6.5.4.6. Environmental Site Design Practice #22: Restore or Daylight Streams at Redevelopment Projects

KEY BENEFITS	USING THIS PRACTICE
• Restores historic drainage patterns and habitats • Provides better runoff attenuation • Helps reduce pollutant loads	• Daylighting should be considered whenever a culvert replacement is scheduled • Stream restoration should also be considered for degraded open streams • Consider runoff pre-treatment and erosion potential of the restored stream

Urban streams are arguably the most extensively degraded and disturbed aquatic systems in North America. Research over the last three decades has revealed that urban development has a profound impact on the hydrology, morphology, water quality and biodiversity of urban streams (Schueler, 1995). The quality of an urban stream depends on the interaction of many different physical and biological processes, each of which is strongly influenced by the degree of impervious cover present in its contributing watershed.

Urban stream degradation is a classic example of the difficulty in addressing long-term environmental change at the local level. Development is a gradual process that spans decades and occurs over a wide region of the landscape. However, it is composed of hundreds of individual development projects completed over a much shorter time-span, which transform just a few acres at a time. Consequently, the true scope of stream degradation may not be fully manifested at the watershed scale for many years.

When viewed from the air, headwater streams dominate the landscape (**Figure 6.101**). Their scale, proximity, and vulnerability to changes in land use make them an excellent choice for local water resources management.

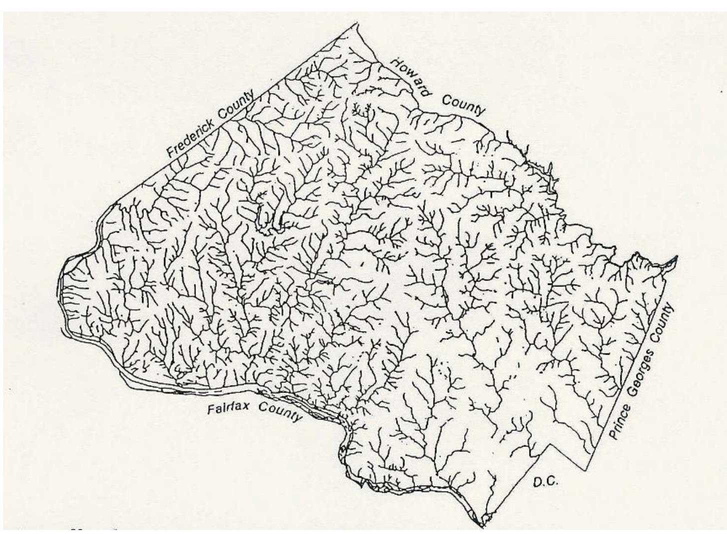


Figure 6.101. Headwater Streams in the Urban Landscape: Montgomery County, Maryland. Source: Schueler (1995)

The commitment to restore a degraded stream on a development or redevelopment site can result in improvements throughout the watershed, especially if done as part of a coordinated local stream system or watershed improvement plan. A restored stream channel connected integrally with its floodplain can be an important part of a design strategy that incorporates the natural drainage system into a sustainable stormwater management system for the site. **Figures 6.102** and **6.103** show before- and after-photos of two different stream restoration projects. These are examples of the kinds of outcomes that can be expected when natural stream channel design concepts are applied.

Figure 6.102. Waukegan Brook Restoration, Washington Park, Michigan
Source: Stormwater Magazine (July-August, 2009)

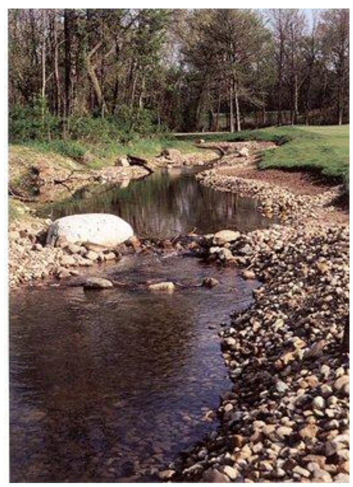


Figure 6.103. Juday Creek, University of Notre Dame Golf Course, South Indiana. Source: Stormwater Magazine, (July-August, 2009)

Where feasible and practical, daylight streams that have been paved or piped to reconnect the streams to the floodplain, restore natural habitats, better attenuate runoff, and help reduce pollutant loads. Daylighting confined streams restores the historic drainage pattern by removing the closed drainage system and constructing a stabilized, vegetated stream. Restored streams also provide educational and recreational opportunities and can help to revitalize neighborhoods. In many ways, paved or piped streams are a metaphor for the way we have "buried" our connection with nature. Daylighting these streams restores not only natural ecological processes, but it can restore a sense of place and the natural importance of water even in the most urban settings (Jessica Hall, Landscape Designer and stream advocate). Prior to taking this step, flooding potential must be carefully evaluated, as well as the potential impact on utilities and the risks associated with contaminated sites.

The following series of photos (**Figures 6.104** through **6.110**) display a stream daylighting project at the Dell, on the grounds of the University of Virginia (UVA).

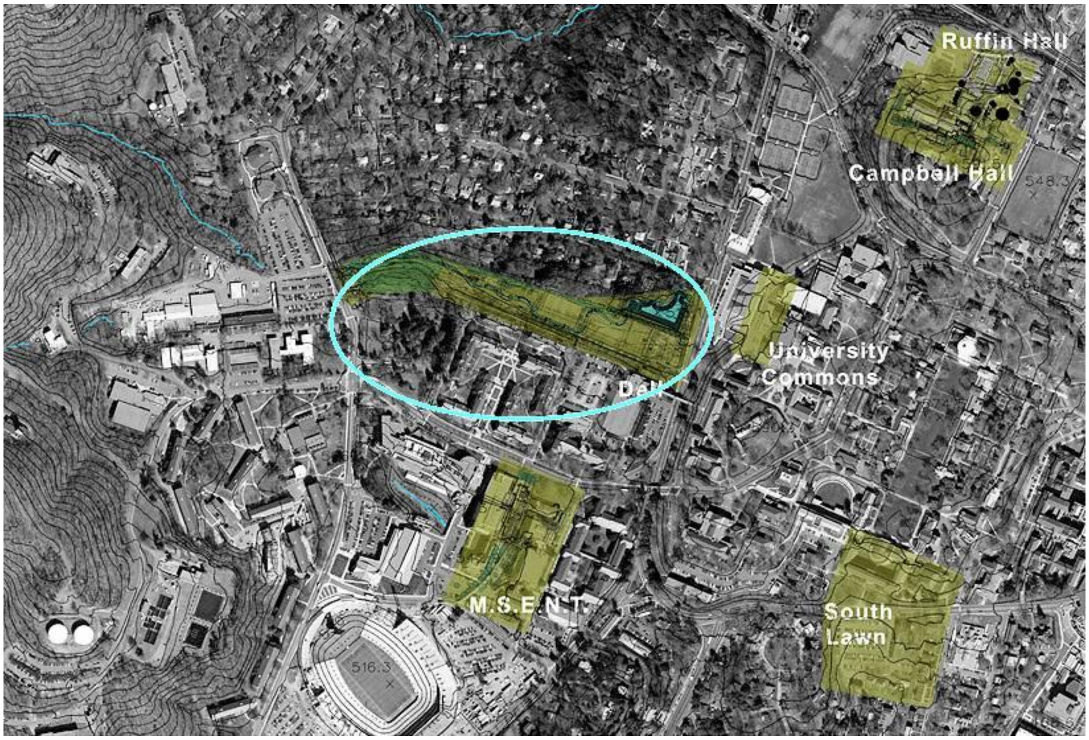


Figure 6.104. Location Map: University of Virginia Stream Daylighting Project (The Dell)
Source: Nelson Byrd Woltz Landscape Architects

Figure 6.105. The UVA Dell Project Site Before Restoration
Source: Nelson Byrd Woltz Landscape Architects

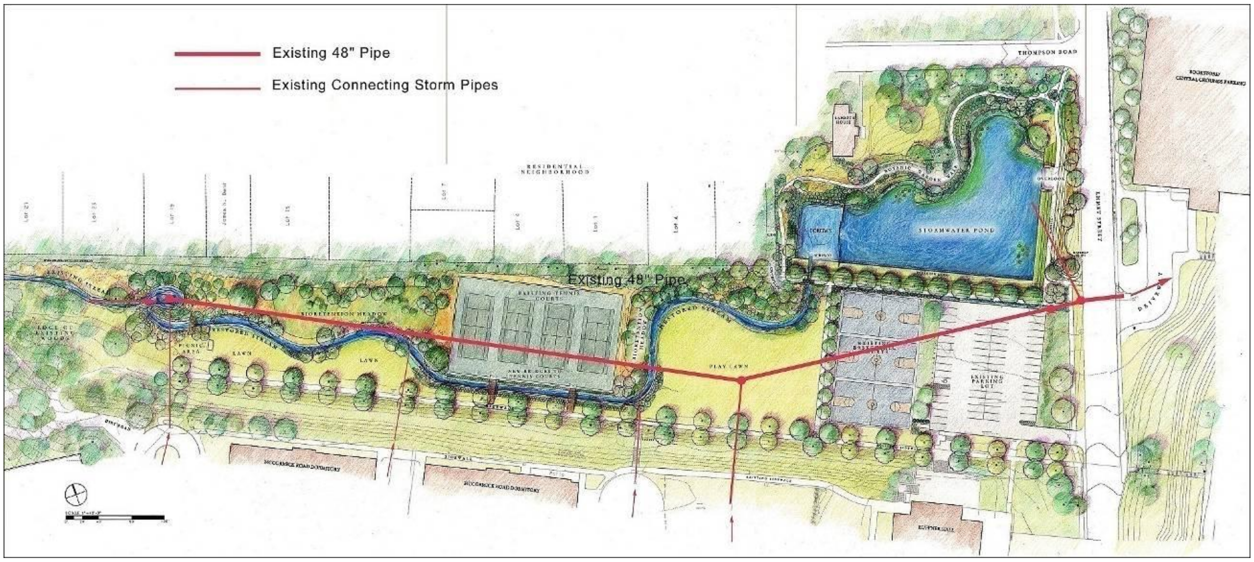


Figure 6.106. The UVA Dell Project Site. Location of the Piped Stream, Connecting Pipes, and the Daylighted Stream Configuration. Source: Nelson Byrd Woltz Landscape Architects

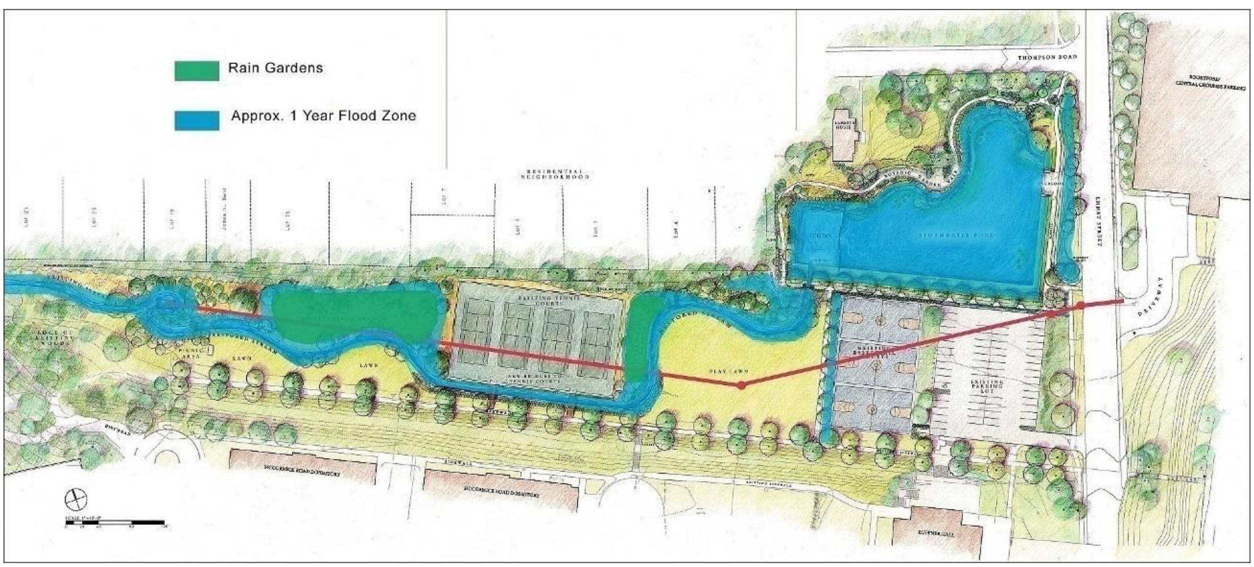


Figure 6.107. UVA Dell Project Site. Location of Rain Gardens and the 1-Year Flood Zone. Source: Nelson Byrd Woltz Landscape Architects

Figure 6.108. UVA Dell Project Site. Location of Rain Gardens and the Maximum Flood Zone.
Source: Nelson Byrd Woltz Landscape Architects

Figure 6.109. UVA Dell Project Site. View of the Stream from Upstream of the Tennis Courts.
Source: Nelson Byrd Woltz Landscape Architects

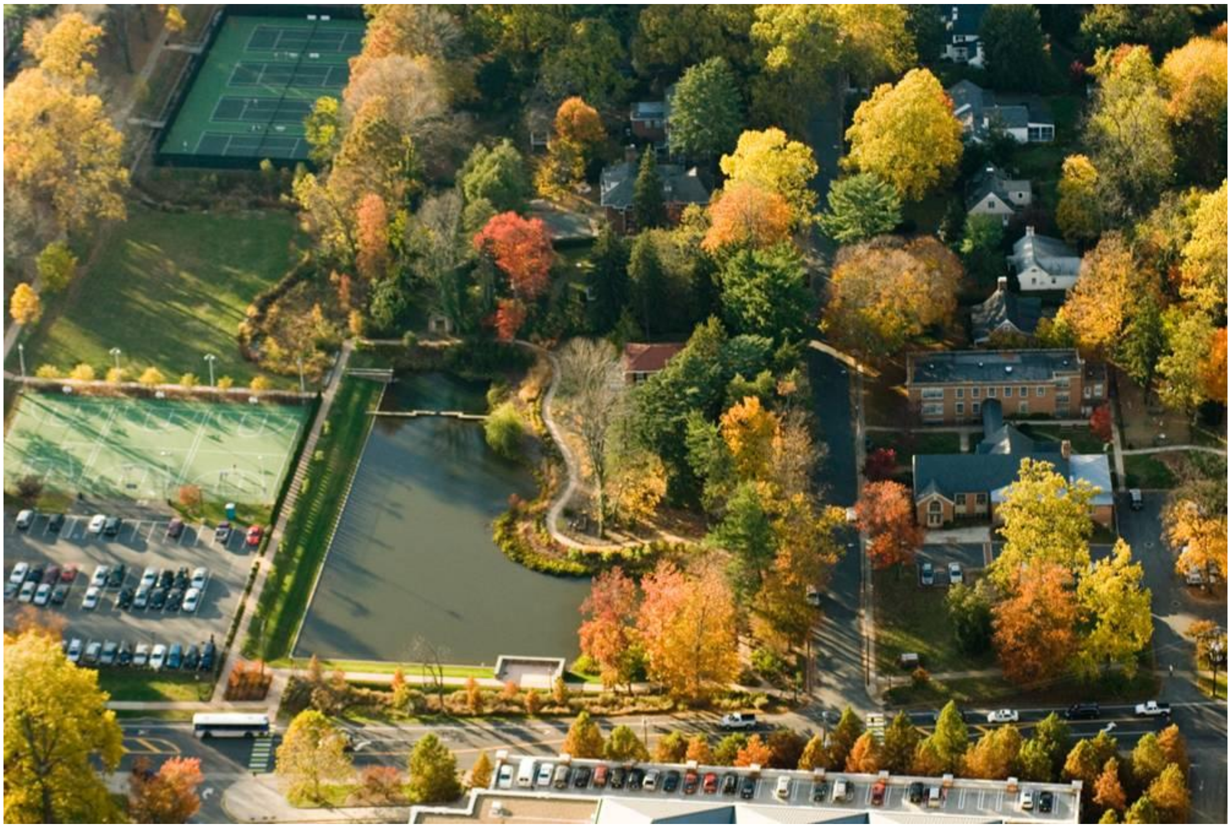


Figure 6.110. UVA Dell Project Site. Daylighted Stream Leading to Pond (lower center).
Source: Nelson Byrd Woltz Landscape Architects

For more in-depth guidance on stream restoration, including procedures to assess existing conditions, refer to the following resources:

- *The Virginia Stream Restoration & Stabilization Best Management Practices Guide*, at: http://www.dcr.virginia.gov/stormwater_management/documents/streamguide.pdf
- *Stream Restoration: A Natural Channel Design Handbook*, at: http://www.bae.ncsu.edu/programs/extension/wqg/srp/sr_guidebook.pdf
- *Stream Restoration Design Handbook (2007)I,* by the USDA-NRCS
- *Restoring Streams in Cities: A Guide for Planners, Policy Makers, and Citizens (1998)*, by A. L. Riley and Luna Leopold

Sustainable Sites Initiative: Applicable Benchmarks and Credits	
Benchmark	**Points**
3.4: Rehabilitate lost streams, wetlands, and shorelines	2 - 5

6.6. OVERCOMING BARRIERS TO ENVIRONMENTAL SITE DESIGN

Despite the clear benefits of ESD techniques, it may be difficult to apply some of them in many communities across the state at the present time. The primary reason is that the geometry, location, and design of development projects is largely dictated by local subdivision codes and zoning ordinances. In some cases, these codes discourage or even prohibit ESD techniques. In other cases, development review authorities are hesitant to approve innovative ESD techniques because of fears they may create real or perceived problems. While potential barriers differ in every community, some frequently cited problems are that ESD techniques may:

- Restrict access for fire trucks and emergency vehicles
- Increase future municipal maintenance costs
- Drive up construction costs
- Make it more difficult to plow snow
- Generate future problems or complaints (e.g. inadequate parking, wet basements, etc.)
- Interfere with existing utilities

These real or perceived local problems must be directly addressed in order to gain widespread adoption of ESD techniques. Communities may also need to carefully reevaluate their local codes and ordinances to overcome barriers to ESD.

Effective methods for promoting code change are to (1) use Code and Ordinance Worksheets to evaluate potential conflicts within local development codes and (2) establish a local site planning roundtable to assist in identifying necessary code changes. Roundtables involve key stakeholders from the local government, development, and environmental communities that influence the development process. These approaches are discussed in detail in **Appendix 3-B** of **Chapter 3** of this Handbook.

6.7. ENVIRONMENTAL SITE DESIGN EXAMPLES

6.7.1. Example 1: Rural Residential Subdivision

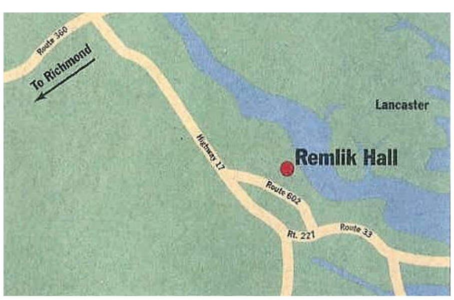


Figure 6.111. Location Map for Remlick Hall Farm/Subdivision

This example, earlier documented in the Chesapeake Bay Foundation's publication ***A Better Way to Grow*** (1996), is located near the hamlet of Remlick, in rural Middlesex County, Virginia. The subdivision is situated on the banks of Lagrange Creek, a tributary of the Rappahannock River, which drains directly into the Chesapeake Bay. **Figure 6.111** is a location map.

Figure 6.112 is an aerial view of the original Remlick Hall Farm site before the development began. **Figure 6.113** is a site plan of the farm under the pre-development conditions.

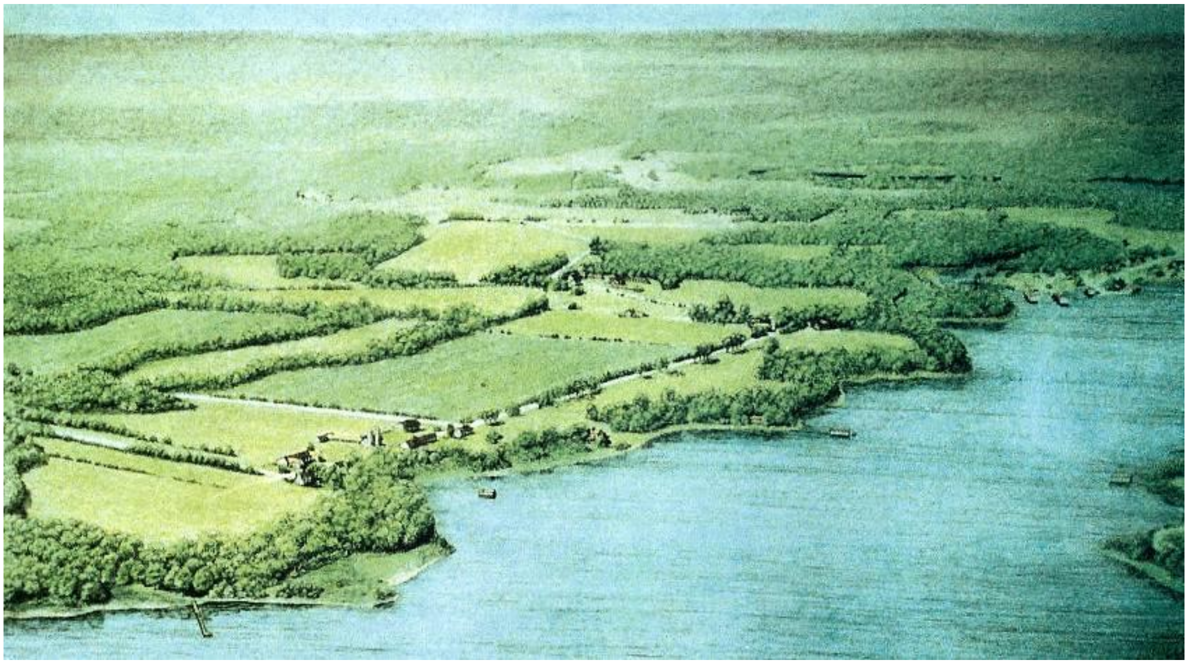


Figure 6.112. Aerial View of Remlick Hall Farm Prior to Development

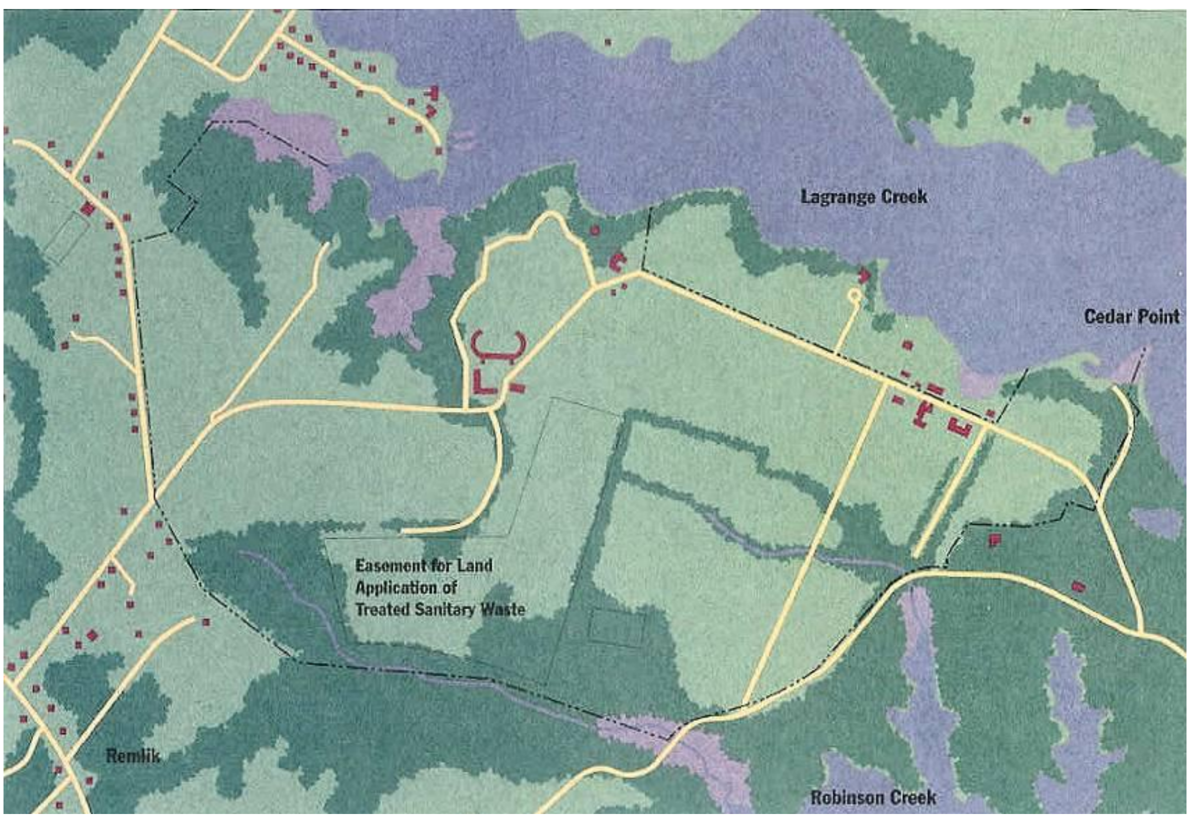


Figure 6.113. Site Plan of Remlick Hall Farm Prior to Development

The Remlick Hall property is a working farm. The farm produces grain crops and hay and also serves as a center for stabling and training horses. Located in the floodplain, the farmland on the property contains prime agricultural soil. Land in the center of the farm has been designated to be fertilized using treated sewage sludge from a nearby subdivision.

The farm and surrounding area is intended for agricultural and rural conservation, according to the Middlesex County comprehensive plan. The county's Low Density Rural Zoning District applies to the property. The zoning permits residential development at a maximum density of one home per 40,000 square feet, which is slightly less than an acre. A stated purpose of the zoning district is the protection of rural character and agricultural and forestry uses. In reality, however, typical development at this density assures the very elimination of the things it is intended to protect.

Clustering development is an effective way to allow development and also save farmland and open space in rural areas undergoing suburbanization. And as far as the Chesapeake Bay is concerned, farmland is preferable to developed land. Properly managed farmland minimizes polluted runoff and maintains the land's permeability to infiltrate stormwater.

The site plan in **Figure 6.114(a)** depicts a layout of residential lots typical of conventional subdivisions. It contains a total of 84 lots: 19 one-acre lots, 58 two- to four-acre lots, and seven lots five- to 15-acres in size. As is typical of conventional subdivisions, most, if not all, of the site is divided into lots. The limited open space that does remain consists of undevelopable land – wetlands and the sewage land application site, which by itself is too small to farm. **Figure 6.114(b)** is an aerial view of this site plan. Even with large lot development, note how much forest cover has been removed, when compared to the view in **Figure 6.112**.

This spread-out development pattern requires 20,250 linear feet of roadway at a VDOT standard width of 20 feet. This translates into 10.83 acres of new impervious surface area on-site for roads and driveways alone. Other hard surfaces and the roof tops associated with each new home contribute yet more impervious surface area, for a total of 26.3 acres. The polluted runoff shed by these surfaces, in combination with the individual septic systems serving the homes, is likely to pollute local waters above and below ground.

The site plan of the cluster subdivision alternative for Remlick Hall, depicted in **Figure 6.115(a)**, contains a total of 52 lots in three clusters. The two westernmost clusters together contain a total of 44 lots with a minimum size of 7,500 square feet, or slightly less than one-sixth of an acre. This lot size requires the use of shared septic facilities – one large drainfield serving a number of homes. The third cluster of homes is grouped near the existing complex of farm buildings and residences at the eastern end of the property. Eight high-end residences occupy lots of approximately one acre in this cluster. **Figure 6.115(b)** is an aerial view of this site plan. When compared to the view in **Figure 6.112**, note that virtually all of the forest cover is preserved.

The cluster plan preserves the rural character, field and shoreline vistas, and large acreages of forest and workable farmland for the enjoyment of all residents. It requires 9,750 linear feet of roadway, a 53 percent reduction in road length from the conventional plan alternative. The cluster plan saves $525,000 in development costs, largely due to the sizable reduction in road length over the conventional plan. Reduction in road length and width (from 20 feet wide to 18 feet) also pays off in less polluted runoff. The original CBF publication documents information regarding land use coverage, stormwater pollutants, and the construction costs of the two alternative plans.

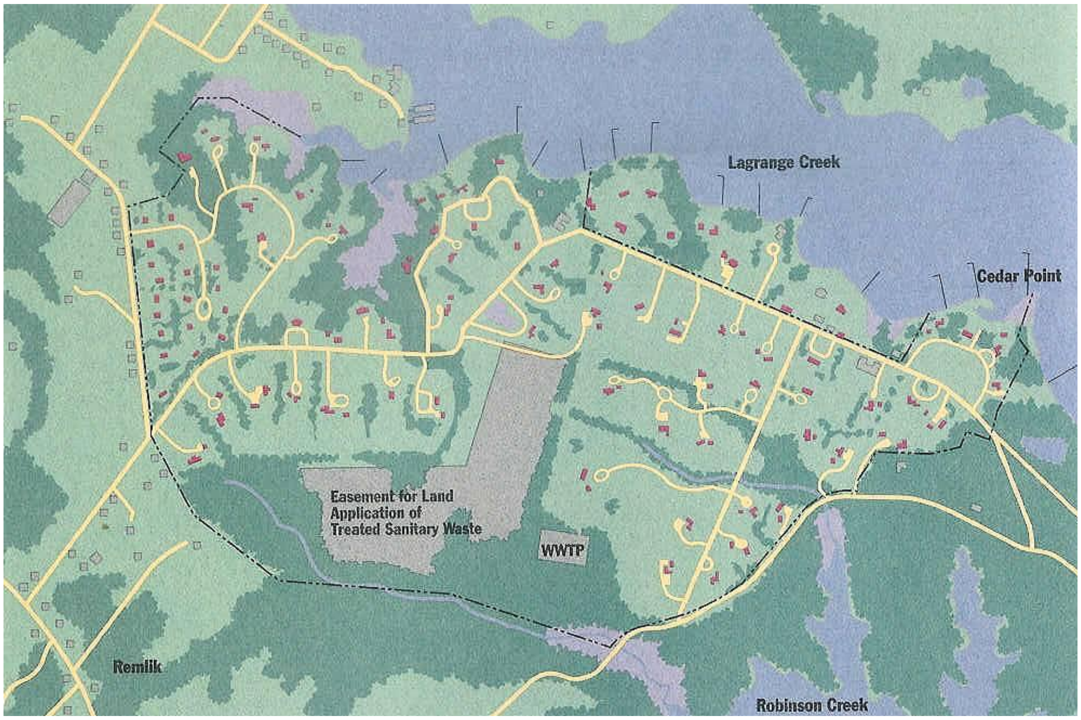
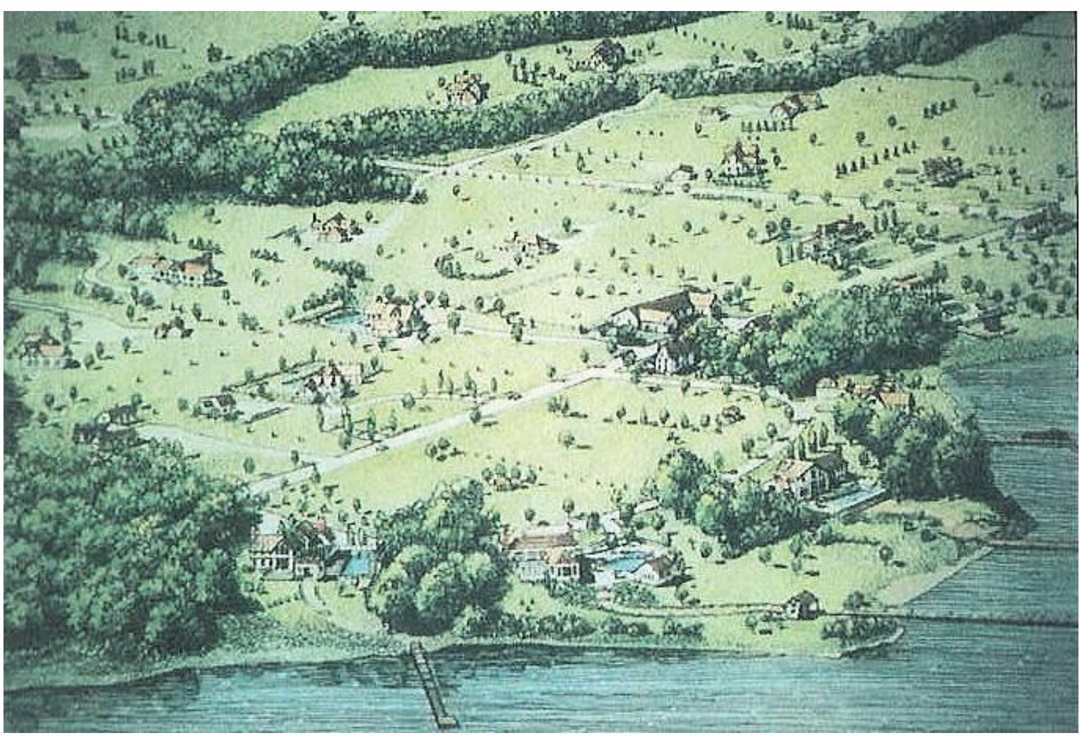


Figure 6.114. Site Plan and Aerial View of Conventional Subdivision Design for Remlick Hall



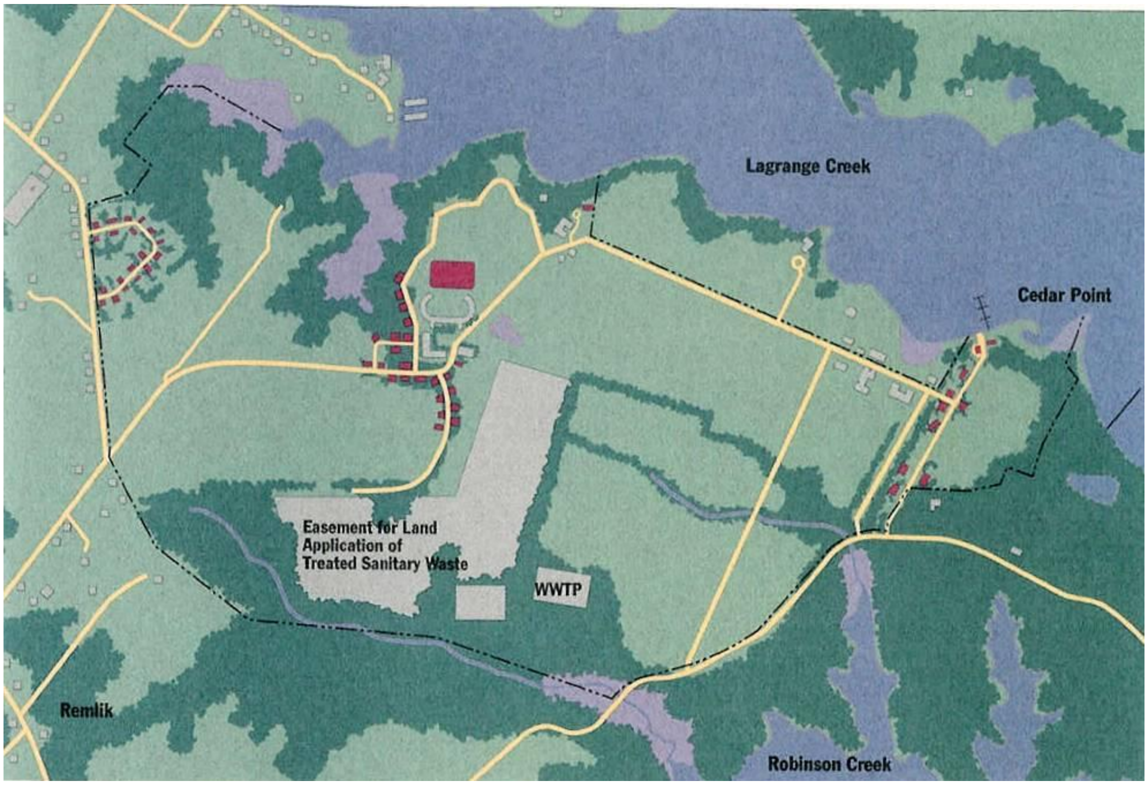


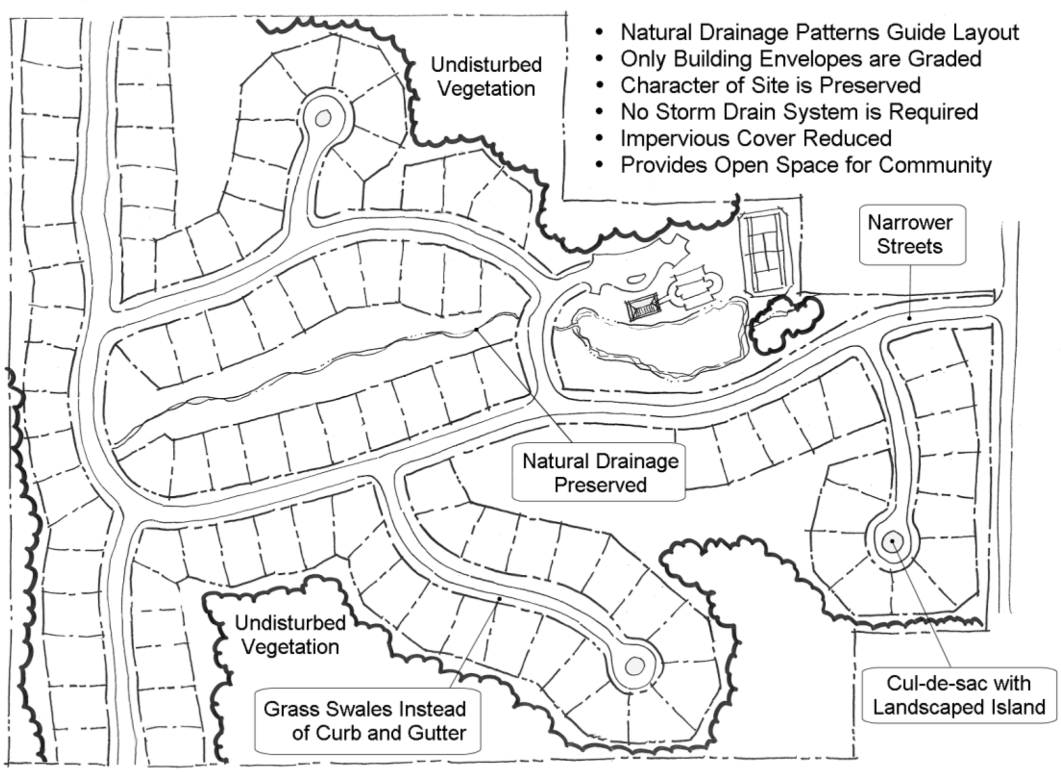
Figure 6.115. Site Plan and Aerial View of Clustering Subdivision Design for Remlick Hall

6.7.2. Example 2: Suburban Residential Subdivision A

A typical residential subdivision design on a parcel is shown in **Figure 6.116(a)**. The entire parcel except for the subdivision amenity area (clubhouse and tennis courts) is used for lots. The entire site is cleared and mass graded, and no attempt is made to fit the road layout to the existing topography. Because of the clearing and grading, all of the existing tree cover, vegetation and topsoil are removed, dramatically altering both the natural hydrology and drainage of the site. The wide residential streets create unnecessary impervious cover and a curb and gutter system that carries stormwater flows to the storm sewer system. No provision for non-structural stormwater treatment is provided on the subdivision site.

A residential subdivision employing stormwater ESD practices is presented in **Figure 6.116(b)**. This subdivision configuration preserves a quarter of the property as undisturbed open space and vegetation. The road layout is designed to fit the topography of the parcel, following the high points and ridgelines. The natural drainage patterns of the site are preserved and are utilized to provide natural stormwater treatment and conveyance. Narrower streets reduce impervious cover and grass channels provide for treatment and conveyance of roadway and driveway runoff. Landscaped islands at the ends of cul-de-sacs also reduce impervious cover and provide stormwater treatment functions. When constructing and building homes, only the building envelopes of the individual lots are cleared and graded, further preserving the natural hydrology of the site.

Figure 6.114. Comparison of a Traditional Residential Subdivision Design (above) with an Innovative Site Plan Developed Using ESD Techniques and Practices (below)



6.7.3. Example 3: Suburban Residential Subdivision B

Another typical residential subdivision design is shown in **Figure 6.117(a)**. Most of this site is cleared and mass graded, with the exception of a small riparian buffer along the large stream at the right boundary of the property. Almost no buffer was provided along the small stream that runs through the middle of the property. In fact, areas within the 100-year floodplain were cleared and filled for home sites. As is typical in many subdivision designs, this one has wide streets for on-street parking and large cul-de-sacs.

The ESD subdivision can be seen in **Figure 6.117(b)**. This subdivision layout was designed to conform to the natural terrain. The street pattern consists of a wider main thoroughfare that winds through the subdivision along the ridgeline. Narrower loop roads branch off of the main road and utilize landscaped islands. Large riparian buffers are preserved along both the small and large streams. The total undisturbed conservation area is close to one-third of the site.

Figure 6.117. Comparison of a Traditional Residential Subdivision Design (above) with an Innovative Site Plan Developed Using ESD Techniques and Practices (below)

6.7.4. Example 4: Suburban Residential Subdivision C

Still another typical residential subdivision design is shown in **Figure 6.118(a)**. Virtually all of the site is cleared and mass graded. The ESD subdivision design shown in **Figure 6.118(b)** provides exactly the same number of lots, but they are smaller and arranged in conformance with the terrain, reducing the cleared area by 40% and the amount of impervious cover by half.

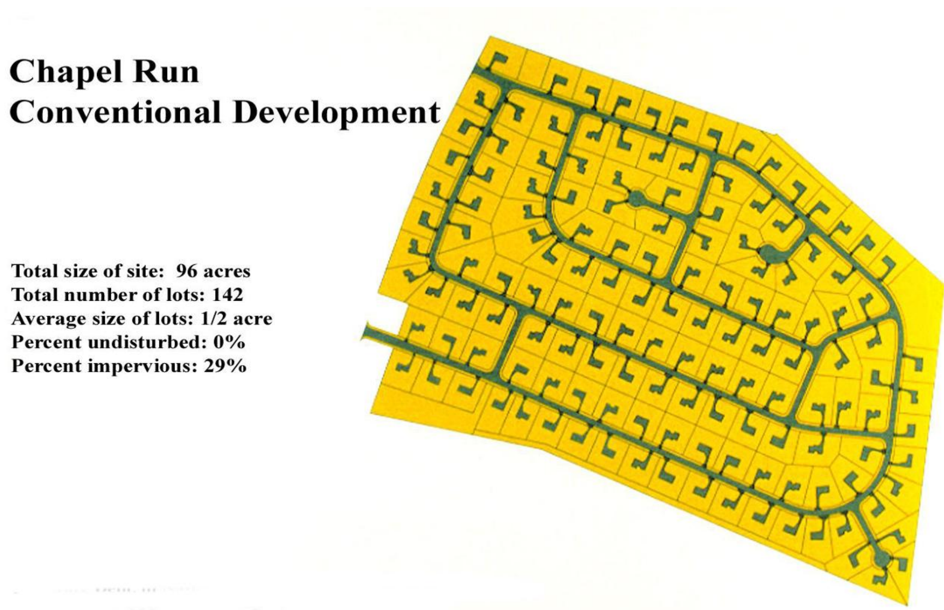
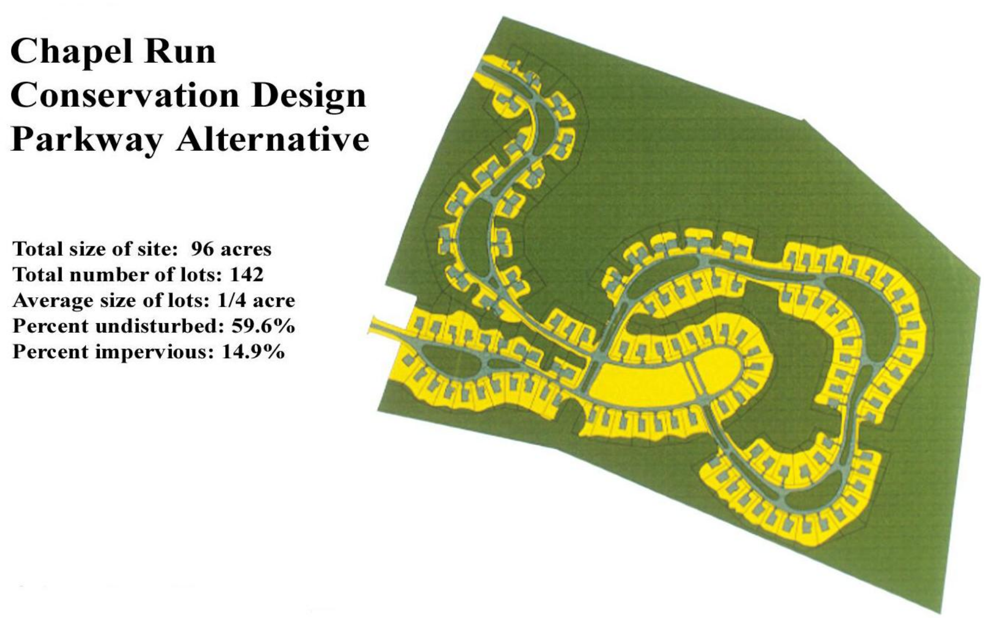


Figure 6.118. Comparison of a Traditional Subdivision Design (above) with an Innovative Site Plan Developed Using ESD Techniques and Practices (below)
Source: Delaware Dept. of Natural Resources and Environmental Control



6.7.5. Example 5: Commercial Development Example

Figure 6.119(a) shows a typical commercial development containing a supermarket, drugstore, smaller shops and a restaurant on an out lot. The majority of the parcel is a concentrated parking lot area. The only pervious area is a small replanted vegetation area acting as a buffer between the shopping center and adjacent land uses. Stormwater quality and quantity control are provided by a wet extended detention pond in the corner of the parcel.

An ESD commercial development can be seen in **Figure 6.119(b)**. Here the retail buildings are dispersed on the property, providing more of an "urban village" feel with pedestrian access between the buildings. The parking is broken up, and bioretention areas for stormwater treatment are built into parking lot islands. A large bioretention area which serves as open green space is located at the main entrance to the shopping center. A larger undisturbed buffer has been preserved on the site. Because of the bioretention areas and buffer provide water quality treatment, only a dry extended detention basin is needed for water quantity control.

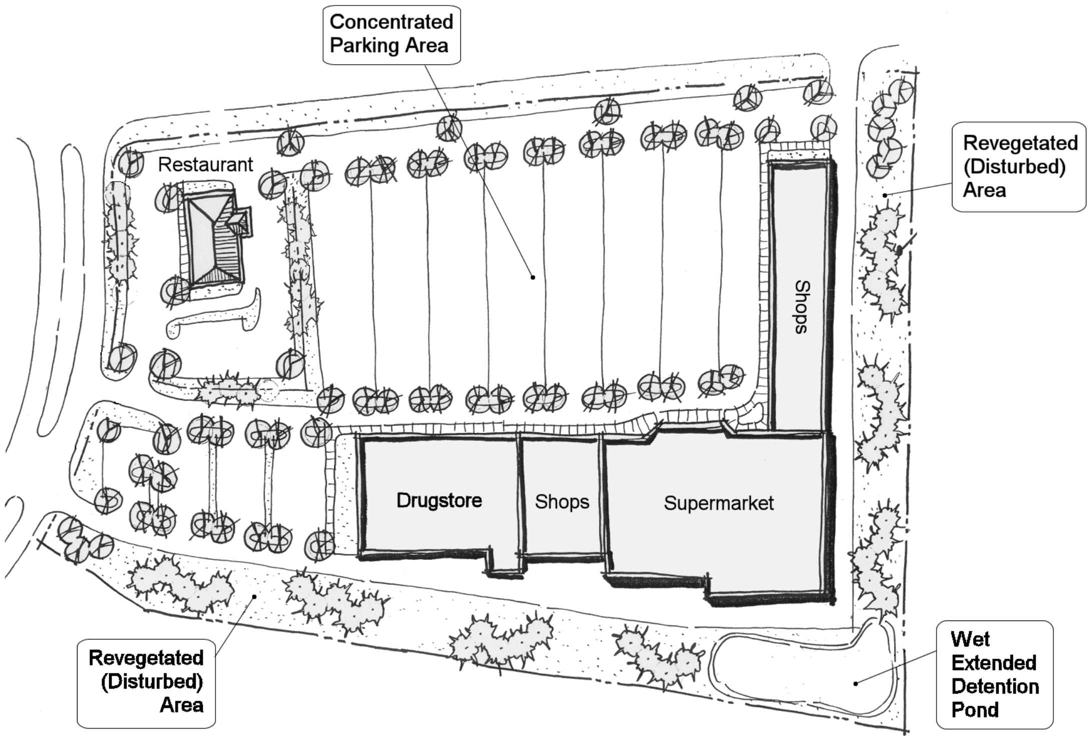
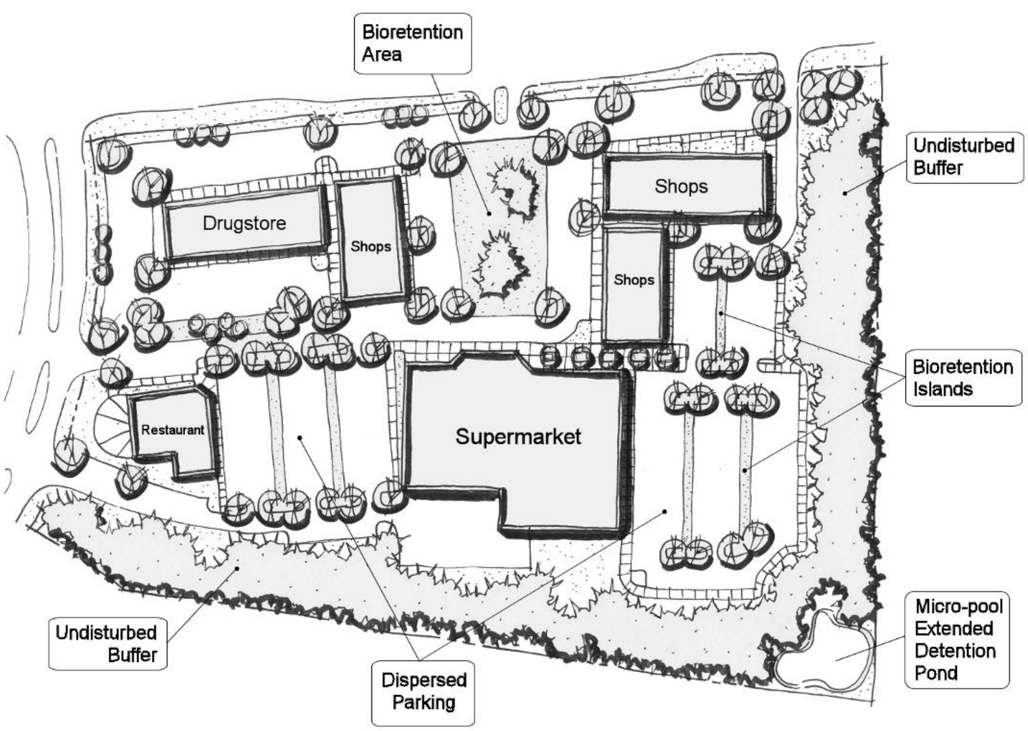


Figure 6.119. Comparison of a Traditional Commercial Development Design (above) with an Innovative Site Plan Developed Using ESD Techniques and Practices (below)



6.7.6. Example 6: Office Park Example

An office park with a conventional design is shown in **Figure 6.120(a)**. Here the site has been graded to fit the building layout and parking area. All of the vegetated areas of this site are replanted areas.

The ESD layout, presented in **Figure 6.120(b)**, preserves undisturbed vegetated buffers and open space areas on the site. Both the parking areas and buildings have been designed to fit the natural terrain of the site. In addition, a modular porous paver system is used for the overflow parking areas.

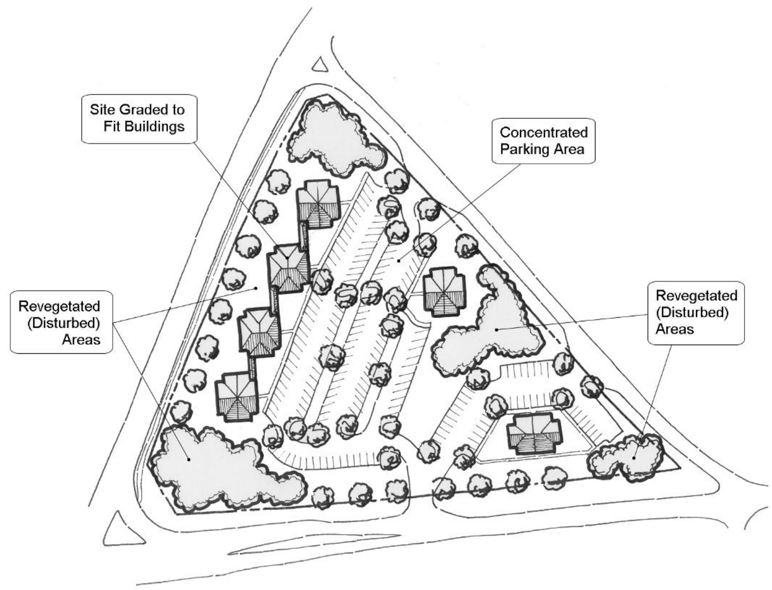


Figure 6.120. Comparison of a Traditional Office Park Design (above) with an Innovative Site Plan Developed Using ESD Techniques and Practices (below)

6.8. OTHER GOOD REFERENCE MATERIAL ON ENVIRONMENTAL SITE DESIGN

There are numerous sources of more specific information regarding Environmental Site Design. The earliest work on the specific topic was a publication by the Center for Watershed Protection entitled ***Better Site Design: A Handbook for Changing Development Rules in Your Community*** (August 1998), which is still available from the Center's website:

http://www.cwp.org/categoryblog/101-better-site-design-.html

The publication entitled ***Better Site Design: An Assessment of the Better Site Design Principles for Communities Implementing Virginia's Chesapeake Bay Preservation Act*** is available from DEQ's website:

http://www.dcr.virginia.gov/stormwater_management/documents/bsd_complete_2007_rev.pdf

For guidance regarding use of environmental design techniques for land development in rural areas, see the book ***Rural By Design*** (Randall Arendt et al., 1994). Perhaps the seminal work on the subject of accommodating man-made structures within the existing natural order in a manner that minimizes impact and cost is Ian McHarg's ***Design with Nature*** (1969).

6.9. PLANNING STORMWATER MANAGEMENT FOR SPECIAL SITE OR CLIMATIC CONDITIONS

Certain kinds of site or climatic conditions create unique challenges regarding site design and BMP selection. Among those are karst geologic conditions, conditions unique to sites near the coastline, sites classified as pollution hotspots, sites where extremely cold winter temperatures and precipitation exist, ultra-urban settings, and sites draining to waters that have exceptional classifications, such as pristine cold water trout streams or polluted waters subject to TMDL waste load allocations. The significance of these kinds of settings for site design is discussed below. The guidance for selecting BMPs in these kinds of settings is provided in **Chapter 8,** entitled **BMP Overview and Selection.**

6.9.1. Karst Geologic Conditions

Karst topography is commonplace in portions of Virginia west of the Blue Ridge, and in small, isolated areas in the Piedmont (see **Figure 6.121**). Karst is a dynamic landscape underlain by soluble bedrock such as limestone, dolomite, and marble. Prior to urbanization, much runoff reaches the epikarst through diffuse infiltration through fractured bedrock (see **Figure 6.122**), and is released slowly into the underlying network of caves. Characteristic karst landscape features include a pinnacled, highly irregular soil-rock interface (Denton, 2008), sinkholes, sinking and disappearing streams, caves, and large springs. Together, these features comprise an interconnected karst hydrological system that is easily contaminated and able to transmit large volumes of water over long distances in a short period of time, frequently passing beneath surface watershed boundaries (Veni et al, 2001; Zokaites, 1997).

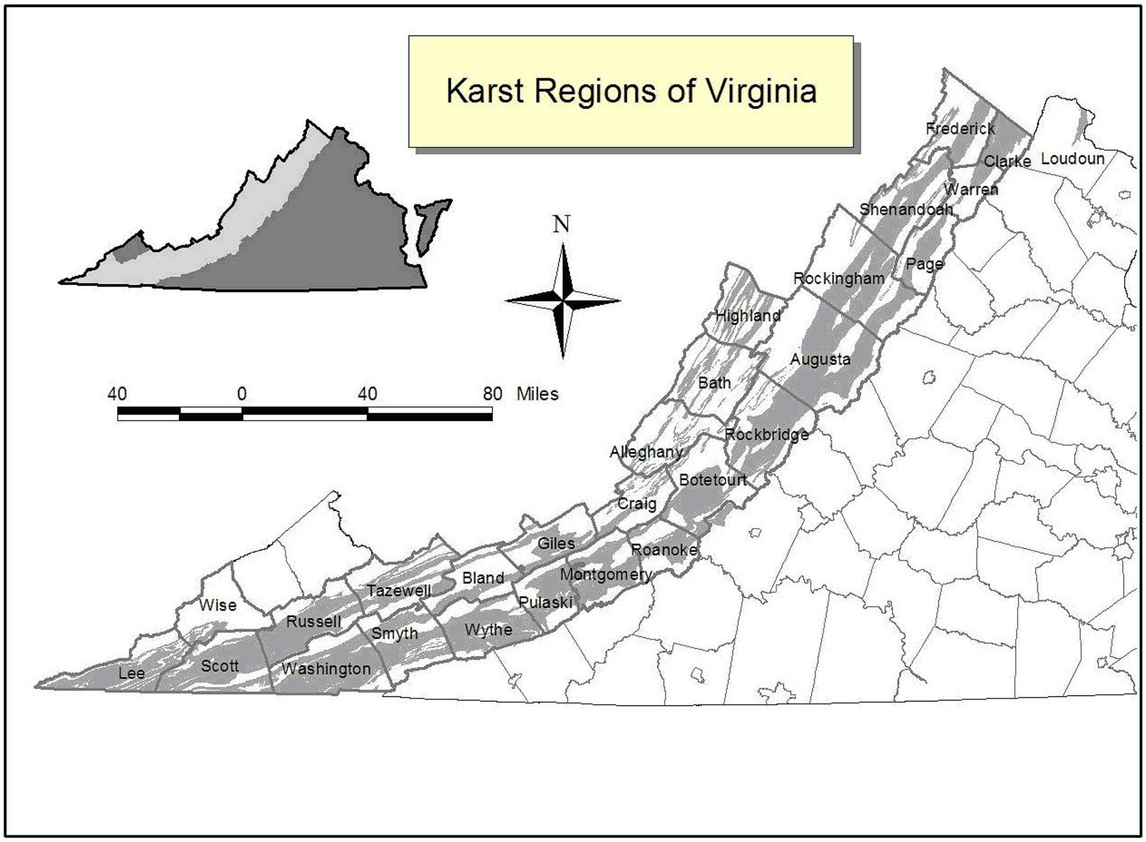


Figure 6.121. Karst Distribution in Virginia

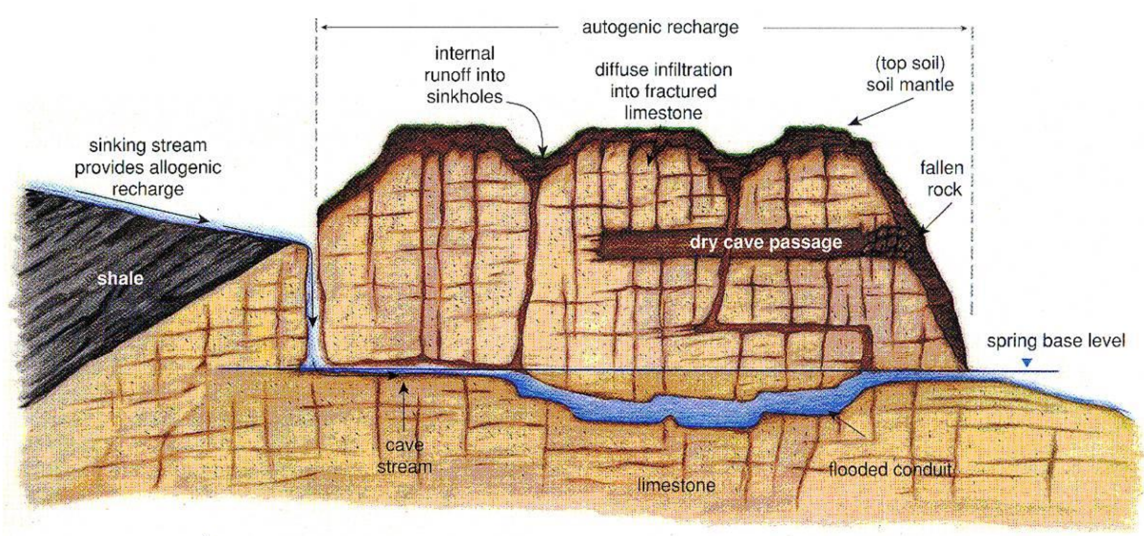


Figure 6.122. Profile Through Typical Karst Geology
Source: White et al. (1995)

The presence of active karst regions in the Ridge and Valley province of Virginia complicates the land development process and requires a unique approach to stormwater design. Some considerations include:

- Post-development runoff rates are greatly increased
- Highly variable subsurface conditions
- Surface/subsurface drainage patterns are poorly understood
- Unique rural development patterns exist in response to karst
- Much higher risk of groundwater contamination
- Risk of stimulating sinkhole formation
- Presence of endangered species

The following general principles should be considered in site layout and the design of stormwater systems in karst regions:

6.9.1.1. For Site Design

- Designers should perform the preliminary and detailed site investigations prior to site and stormwater design to fully understand subsurface conditions, assess karst vulnerability and define the actual drainage pattern present at the site. Any existing sinkholes should be surveyed and permanently recorded on the property deed. In addition, an easement, buffer or reserve area should be identified on the development plats for the project so that all future landowners are aware of the presence of active karst on their property.

- Minimize site disturbance and changes to the soil profile, including cuts, fills, excavation and drainage alteration.

- Sediment traps and basins should only be used as a last resort after all other E&S control options have been considered and rejected. In the rare instance they are employed, they should serve small drainage areas (2 acres or less), be located away from known karst features, and be equipped with impermeable liners to discourage subsidence.

- Minimize the amount of impervious cover created at the site so as to reduce the volume and velocity of stormwater runoff generated.

- Take advantage of topography when locating building pads and place foundations on sound bedrock.

6.9.1.2. For Stormwater Design

- Treat runoff as sheetflow in a series (treatment train) of small runoff reduction practices before it becomes concentrated. Practices should be designed to disperse flows over the broadest area possible to avoid ponding or soil saturation.

- Small scale LID-type practices work best in karst areas, although they should be shallow, closed and sometimes lined to prevent groundwater interaction. For example, micro-bioretention and infiltration practices are a key part of the treatment train. Distributed treatment is recommended over centralized stormwater facilities, which are defined as any practice that treats runoff from a contributing drainage area greater than 20,000 square feet of impervious cover, and/or has a surface ponding depth greater than three feet. Examples include wet ponds, dry extended detention ponds, and infiltration basins.

- The use of these centralized practices is strongly discouraged, even when liners are used. Centralized treatment practices require more costly geotechnical investigations and design features than smaller, shallower distributed LID-type practices. In addition, distributed, disconnected LID practices eliminate the need to obtain an underground injection permit from the USEPA**.**

- Any discharge to karst features should only occur downstream of other BMP's and ensure that such discharges meet all relevant criteria of the Virginia Stormwater Management Regulations. The receiving feature should be identified on the permit registration as the receiving water. Developers should check with the Virginia Karst Office in the Virginia Department of Conservation and Recreation's Division of Natural Heritage to see if the resurgence location (where water entering the sinkhole returns to the surface at a spring) has been determined. If not, the developer is encouraged to coordinate with the Karst Office to perform dye trace investigations to locate the resurgence(s). Consistent with federal environmental regulations at 40 C.F.R. parts 144-148, some karst features receiving runoff may be considered class V injection wells and would have to be registered as such with EPA Region III. To ensure compliance in cases where stormwater runoff is discharged to a karst feature, DEQ recommends coordination with EPA Groundwater & Enforcement Branch (3WP22), U.S. EPA Region 3, 1650 Arch Street , Philadelphia, PA 19103, Phone: (215) 814-5427, Fax: (215) 814-2318.

For more detail regarding the effects of karst on site and stormwater design, see **Appendix 6-B** of this chapter, entitled *Stormwater Design Guidelines for Karst Terrain in Virginia*.

6.9.2. Coastal Plain/High Groundwater Table

Most stormwater practices were originally developed in the Piedmont physiographic region and have seldom been adapted for much different conditions in the coastal plain. Consequently, guidance for stormwater design is strongly oriented toward the rolling terrain of the Piedmont with its defined headwater streams, deeper groundwater table, low wetland density, and well drained soils.

By contrast, stormwater design in the coastal plain is strongly influenced by unique physical constraints, pollutants of concern and resource sensitivity of the coastal waters. Implementation of traditional stormwater practices in the coastal plain is constrained by physical factors such as flat terrain, high water table, altered drainage, extensive groundwater interactions, poorly-drained soils, and extensive wetland complexes. The significance of these constraints is described below:

Flat Terrain. From a hydrologic standpoint, flat terrain increases surface water/groundwater interactions and reduces the hydraulic head available to treat the quality of stormwater or move floodwaters through the watershed during the intense tropical storms and hurricanes for which the region is especially prone.

High Water Table. In much of the coastal plain, the water table exists within a few feet of the surface. This strong interaction increases the movement of pollutants through shallow groundwater and diminishes the feasibility or performance of many stormwater control practices.

Highly Altered Drainage. The headwater stream network in many coastal plain watersheds no longer exists as a natural system, with most zero order, first order and second order streams replaced by ditches, canals and roadway drainage systems.

Poorly Drained Soils. Portions of the coastal plain have soils that are poorly drained and frequently do not allow infiltration to occur and, as a result, coastal plain watersheds contain have a greater density of wetlands than any other physiographic region in the country (Dahl, 2006).

Very Well-Drained Soils. In other parts of the coastal plain, particularly near the coast line, soils are sandy and extremely permeable, with infiltration rates exceeding four inches per hour or more, providing a stronger risk of stormwater pollutants rapidly migrating into groundwater. This is a particular design concern, given the strong reliance in the coastal plain on groundwater for drinking water supply.

Drinking Water Wells and Septic Systems. A notable aspect of the coastal plain is a strong reliance on public or private wells to provide drinking water (USGS, 2006). As a result, *designers need to consider groundwater protection as a first priority* when they are considering how to dispose of stormwater. At the same time, development in the coastal plain relies extensively on septic systems or land application to treat and dispose of domestic wastewater. Designers need to be careful in how they manage and dispose of stormwater so they do not reduce the effectiveness of adjacent septic systems.

Conversion of Croplands With Land Application. Land application of animal manure and domestic wastewater on croplands is a widespread practice across the coastal plain. When this farmland is converted to land development, there is a strong concern that infiltration through nutrient enriched soils may actually increase nutrient export from the site.

Pollutants of Concern. The key pollutants of concern in coastal plain watersheds are nitrogen, bacteria, and metals. These pollutants have greater ability to degrade the quality of unique coastal plain aquatic resources such as shellfish beds, swimming beaches, estuarine and coastal water quality, seagrass beds, migratory bird habitat, and tidal wetlands. Yet, the design of many stormwater practices is still rooted in phosphorus control.

Unique Development Patterns. The development patterns of coastal plain watersheds are also unique, with development concentrated around waterfronts, water features and golf courses rather than around an urban core. The demand for vacation rental, second homes and retirement properties also contributes to sprawl-type development.

Shoreline Buffers and Critical Areas. Chesapeake Bay Preservation Areas (CBPAs) in Virginia include special shoreline buffer and stormwater pollutant reduction requirements that strongly influence how stormwater practices are designed and located. In addition, the predominance of shoreline development often means that stormwater must be provided on small land parcels a few hundred feet from tidal waters. Consequently, many development projects within CBPAs must rely on stormwater micro-practices to comply with applicable requirements.

The Highway as the Receiving System. The stormwater conveyance system for much of the coastal plain is frequently tied to the highway ditch system, which is often the low point in the coastal plain drainage network. New upland developments often must get approvals from highway authorities to discharge to their drainage system, which may already be at or over capacity with respect to handling additional stormwater runoff from larger events. The requirement for developers to obtain both a local government and highway agency approval for their project can result in conflicting design requirements.

Sea Level Rise. Sea level is forecast to rise at least a foot over the next thirty to fifty years as a result of subsidence and climate change. This large change in average and storm elevations in the transition zone between tidal waters and the shoreline development a few feet above it has design implications for the choosing where to discharge treated stormwater.

Hurricanes and Flooding. Due to their location on the coast, coastal communities are subject to rainfall intensities that are 10-20 percent greater for the same design storm event compared to sites further inland. The flat terrain lacks enough hydraulic head to quickly move water out of the conveyance system (which may be further complicated by the backwater effects of tidal surges). Additionally, large tidal surges may cause significant flooding with no precipitation present.

Guidance for BMP selection based on a high groundwater table or the filtration rate of soils is provided in **Table 8.4** in **Chapter 8**.

6.9.2.1. General Stormwater Design Principles in the Coastal Plain

The following initial guiding principles are offered on the design of stormwater practices in the coastal plain:

- Use micro-scale and small-scale practices for development projects within 500 feet of shoreline or tidal waters.
- Keep all other practices out of the riparian buffer area, except for the use of conservation filters at their outer boundary.
- Relax some design criteria to keep practice depths shallow and respect the water table.
- Emphasize design factors that can increase bacteria removal, not exacerbate bacteria problems.
- To maximize nitrogen removal, promote denitrification by creating anaerobic and aerobic zones adjacent to one another in either the vertical or lateral direction.
- Use plant species that reflect the native coastal plain plant community and, in particular, can survive well in a high salinity environment.
- Take a linear design approach to spread treatment along the entire length of the drainage path, from the rooftop to tidal waters, maximizing the use of in-line treatment in the swale and ditch system.

- Consider the effect of sea level rise on future elevations of stormwater practices and infrastructure. In some cases, it may make more sense to use site design to "raise the bridge" by increasing the vertical elevation of building pads at coastal plain development sites.

For more detail regarding the effects of coastal settings on site and stormwater design, see **Appendix 6-C** of this chapter, entitled *Stormwater Design in the Coastal Plain of Virginia*.

6.9.3. Pollution Hot Spots

Certain classes of business, municipal and industrial operations, if not carefully managed, produce higher concentrations of certain pollutants (e.g., nutrients, hydrocarbons, metals, chlorides, pesticides, bacteria, trash, etc.) than are normally found in urban runoff. Such facilities, commonly called pollution *Hotspots*, also present a greater potential risk for spills, leaks or illicit discharges. Hotspot facilities are required to obtain discharge permits and maintain a series of pollution control practices to prevent or minimize contact of pollutants with rainfall and runoff.

Examples of business, municipal and industrial activities that may be considered hotspots and need pollution prevention permits and plans include:

- Gasoline/fueling stations (**Figure 6.123**)
- Vehicle Repair Facilities
- Vehicle washing/steam cleaning sites
- Auto recycling facilities and junk yards
- Commercial laundry and dry cleaning
- Commercial nurseries
- Golf Courses
- Swimming Pools
- Heavy manufacturing/power generation
- Metal production, plating and engraving
- Toxic chemical manufacturing/storage
- Petroleum storage and refining facilities
- Airports and deicing facilities
- Marinas and ports
- Railroads and rail yards

CERCLA-designated superfund sites

- Hazardous waste handling, transfer and disposal facilities
- Recycling and solid waste handling and transfer facilities
- Composting facilities
- Landfills
- Incinerators
- Vehicle/equipment/fleet maintenance and parking areas
- Public works yards and material storage areas (**Figure 6.124**)
- Public Buildings (e.g., Schools, Libraries, Police and Fire Stations)
- Water/Wastewater Treatment Facilities

Figure 6.123. Gasoline Station

Figure 6.124. Public Works Yard

Hotspot facilities should be evaluated to identify their potential pollution-generating activities. There are typically six categories of pollution-generating activities that commonly contribute to stormwater problems (see **Figure 6.125**):

- Outdoor materials handling
- Physical plant maintenance
- Stormwater infrastructure
- Turf/landscape management
- Vehicle operations
- Waste management

Figure 6.125. Six Categories of Pollution-Generating Activities Assessed at Stormwater Hotspot Facilities

Training of personnel at the affected area is needed to ensure that industrial and municipal managers and employees understand and implement the correct stormwater pollution prevention practices needed for their site or operation. Both industrial and municipal operations must develop detailed stormwater pollution prevention plans (SWPPPs), train employees, and submit reports to regulators.

Stormwater management implications for hot spot sites are as follows:

- The main focus regarding potential pollutants must be on shelter (from the elements – see **Figure 6.126**) and containment of potential spills and illicit discharges (**Figure 6.127**)
- Certain stormwater control measures (e.g., infiltration) should be avoided
- The practices that are applied will typically require some sort of pre-treatment (e.g., a sand filter) before runoff is allowed to be discharged to a natural channel, a storm sewer or, most important, any type of infiltration practice.

Figure 6.126. Covered Chemical Storage

Figure 6.127. Wash Water Containment

Table 8.3 in **Chapter 8** is a matrix that indicates which control measures are appropriate for use at hotspot locations.

The following are excellent sources of information related to managing stormwater and pollution at hotspot-type settings:

- ***Issue Paper H: Potential Stormwater Hotspots, Pollution Prevention, Groundwater Concerns and Related Issues, version 3 (final)***, prepared by Emons & Oliver Resources and the Center for Watershed Protection for the Minnesota Pollution Control Agency, from which the document is available online at: http://www.pca.state.mn.us/publications/wq-strm8-14bf.pdf
- ***Urban Subwatershed Restoration Manual 9, Chapter 4: Hotspot Facility Management***, available from the Center for Watershed protection online at: http://www.cwp.org/Resource_Library/Center_Docs/municipal/USRM9.pdf
- ***Stormwater Management Manual for Western Washington, Volume IV: Source Control BMPs*** (February 2005 , Publication No. 05-10-32, which is a revised portion of Publication No. 91-75) available online from the Washington State Department of Ecology's Water Quality Program at: http://www.ecy.wa.gov/pubs/0510032.pdf
- ***Development Planning for Storm Water Management: A Manual for the Standard Urban Storm Water Mitigation Plan (SUSMP)***, available from the Los Angeles County (California) Department of Public Works online at: http://ladpw.org/wmd/npdes/SUSMP_MANUAL.pdf

6.9.4. Cold Winter Climate

In parts of Virginia, colder temperatures and longer lasting snow and ice events occur during the winter. Regions that have an average daily temperature of 35 degrees Fahrenheit or less during January, and that have a growing season less than 120 days, are especially vulnerable to the effects of cold weather. While Virginia's average growing season is rarely less than 160 days, the statewide average temperature for January is just above 35^{o}F. This means that some areas are colder, illustrated by the typically bitterly cold temperatures of the northern Blue Ridge, which are more like January temperatures in Chicago.

Cold climates can present additional challenges to the selection, design and maintenance of stormwater management BMPs due to one or more of the factors listed in **Table 6.21** below. While there may be fewer runoff events during winter months, snow and ice may significantly impact the operation of some treatment practices during winter rain events and periods of snowmelt. Engineers and site designers in cold regions should be aware of these challenges and make provisions for them in their final designs.

Table 6.21. Cold Weather Challenges to BMP Selection and Design

Climatic Conditions	BMP Selection/Design Challenge
Cold Temperatures	• Pipe freezing • Permanent pool covered by ice • Reduced biological activity • Reduced oxygen levels during ice cover • Reduced settling velocities • Impacts of road salt/deicers/chlorides • Winter sanding impacts on facilities
Deep Frost Line	• Frost heaving • Reduced soil infiltration • Pipe freezing
Significant Snowfall	• High runoff volumes during snowmelt • High runoff during rain-on-snow • High pollutant loads during spring melt • Other impacts of road salt/deicers/chlorides • Snow management may affect BMP storage • Winter sanding impacts on facilities

Source: Adapted from Washington (State) Department of Ecology (2004)

The following describe in more detail some of the potential cold climate impacts:

Frost Heaving. Moisture in the soil expands when it freezes, causing the soil to rise or “heave.” This creates the potential for damage to structural components of BMPs, such as pipes or concrete infrastructure located within the soil. Another concern is that infiltration BMPs can cause frost heave damage to other structures, particularly roads. The water infiltrated into the soil matrix can flow under a permanent structure and then re-freeze. The sudden expansion associated with this freezing can cause damage to above-ground structures.

Pipe Freezing. Most treatment practices, with the exception of vegetative filter strips, rely on some form of inlet piping and may also have an outlet or underdrain pipe. Frozen pipes can crack due to ice expansion, creating a maintenance or replacement burden. In addition, pipe freezing reduces the hydraulic capacity of the system, thereby limiting pollutant removal and creating the potential for flooding (CWP, 1997).

Ice Formation on a Permanent Pool. The permanent pool of a wet pond serves several purposes. First, the water in the permanent pool slows down incoming runoff, allowing for increased settling of pollutants. In addition, the biological activity in the pool can act to remove nutrients, since growing algae, plants and bacteria require these nutrients for growth. In some systems, such as sand filters, a permanent pool acts as a pre-treatment measure, settling out larger sediment particles before full treatment by the BMP.

Ice cover on a permanent pool causes two problems. First, the treatment pool’s volume is reduced. Second, because the permanent pool is frozen, it acts as an impermeable surface.

Runoff entering an ice-covered pond can follow two possible routes, neither of which provides sufficient pollutant removal. In the first case, runoff is forced under the ice, causing scouring of bottom sediments. In the second case, runoff flows over the top of the ice, receiving little or no treatment. Sediment that settles on top of the ice can easily be re-suspended by subsequent runoff events (CWP, 1997).

Reduced Settling Velocities. Settling is the most important removal mechanism in many BMPs. As water becomes cooler, its viscosity increases, which reduces particle velocity by up to 50 percent and makes it more difficult for particles to settle out.

Reduced Biological Activity. Many stormwater treatment practices rely on biological mechanisms to help reduce pollutants, especially nutrients and organic matter. For example, wetland systems rely on plant uptake of nutrients and the activity of microbes at the soil/root zone interface to break down pollutants. During cold temperatures (below 40°F), photosynthetic and microbial activity is sharply reduced when plants are dormant during the non-growing season, limiting these pollutant removal pathways (CWP, 1997).

Reduced Oxygen Levels in Bottom Sediments. In cold regions, oxygen exchange between the air-water interface in ponds and lakes is restricted by ice cover. In addition, warmer water sinks to the bottom during ice cover, because it is denser than the cooler water near the surface. Although biological activity is limited in cooler temperatures, the decomposition that takes place does so at the bottom of wet ponds, sharply reducing oxygen concentrations in bottom sediments. In these anoxic conditions, positive ions retained in sediments can be released from bottom sediments, reducing the BMP’s ability to treat these nutrients or metals in runoff.

Reduced Soil Infiltration. The rate of infiltration in frozen soils is limited, especially when ice lenses form (CWP, 1997). There are two results of this reduced infiltration. First, BMPs that rely on infiltration to function can be ineffective when the soil is frozen. Second, runoff volume from snowmelt is elevated when the ground underneath the snow is frozen.

Increased Pollutant Loading During Winter or Spring Thaw Periods. Winter or spring melt events are important because of increased runoff volumes and pollutant loads. The snowpack contains high pollutant concentrations, due to the buildup of pollutants over a several-month period. Chloride loadings are highest in snowmelt events because of the use of deicing salts, such as sodium chloride and magnesium chloride. Excessive loadings can kill vegetation in swales and other vegetative BMPs. Research indicates roughly 65 percent of the annual sediment, organic, nutrient, and lead loads can be attributed to winter and spring melts.

Access Difficulties in Ice and Snow. Points of access to BMPs may be frozen shut, and BMPs and access ways may be buried under the snow.

Particular Maintenance Issues. Maintenance requirements of certain BMPS may increase during the winter months due to increased loading and debris. Pollutant loading typically increases due to leaf fall, snow plowing, sanding, salting, and accumulation of materials in snow piles. Unique cold climate pollutants include the following:

- Sand
- Salt
- Polycyclic Aromatic Hydrocarbons (PAHs) emitted from fireplaces and inefficient vehicles in the winter
- Cyanide included in deicing salt compounds to prevent clumping

BMPs that use filtration, settling, or trapping to remove contaminants require frequent inspection and maintenance. Regular maintenance of BMPs located in cold climates is suggested just prior to the first snowfall or road sanding, after the last snowfall, and during spring snowmelt to ensure the proper treatment of runoff.

Each of the individual stormwater control measure specifications on the Virginia Stormwater BMP Clearinghouse web site includes guidance for mitigating the potential effects of cold weather on treatment practice operation and performance. Furthermore, guidance for BMP selection based tolerance for winter conditions is provided in **Table 8.5** in **Chapter 8**. The following are excellent sources of more detailed information related to managing stormwater and pollution in cold climates:

- ***Issue Paper G:. Cold Climate Considerations for Surface Water Management***, prepared by Emons & Oliver Resources and the Center for Watershed Protection for the Minnesota Pollution Control Agency, from which the document is available online at: http://www.pca.state.mn.us/publications/wq-strm8-14be.pdf
- ***Stormwater BMP Design Supplement for Cold Climates***, by D. Caraco and R. Claytor, available online from the Center for Watershed Protection at: http://www.cwp.org/Resource_Library/Center_Docs/special/ELC_coldclimates.pdf
- ***Snow, Road Salt and the Chesapeake Bay***, available online from the Center for Watershed Protection at: http://www.cwp.org/Resource_Library/Special_Resource_Management/ColdClimate/snow_roadsalt_chesbay.pdf
- ***Stormwater Management Manual for Eastern Washington***, Publication No. 04-10-076, available online from the Washington State Department of Ecology at: http://www.ecy.wa.gov/pubs/0410076.pdf .
- ***New York State Stormwater Management Design Manual, Appendix I***, available online from the New York State Department of Environmental Conservation at: http://www.dec.ny.gov/docs/water_pdf/swdmappendixi.pdf

6.9.5. Cold-Water Fisheries and Other Sensitive Receiving Waters

Cold and cool water streams have habitat qualities capable of supporting trout and other sensitive aquatic organisms. Waters of Virginia are classified in seven (7) classes in the Virginia Water Quality Standards (WQS, at 9 VAC 25-260 et seq.), administered by the State Water Control Board and the Department of Environmental Quality. Cold water fisheries fall into Classes V and VI. Class V streams are appropriate for stocking trout. Class VI streams accommodate natural trout populations. Both of these stream classes have stricter criteria for water temperature and dissolved oxygen than other classes of water in the state (9 VAC 25-260-60 and 9 VAC 25-260-70). This applies both to the typical conditions that apply to these stream classes as well as to the limit of variation in these criteria. Furthermore, § 9 VAC 25-260-370 B of the WQS describes the Virginia Department of Game and Inland Fisheries more discrete classification of trout waters and the distinctions between them. Finally, PART IX (§ 9 VAC 25-260-360 et seq.) of the WQS provides a Virginia map divided into regions and lists each named stream segment within each region, identifying for each the stream class and critical criteria that apply.

The design objective for the cold water (trout) streams is to maintain habitat quality by preventing stream warming, maintaining dissolved oxygen levels, maintaining natural recharge, preventing pollution, preventing bank and channel erosion, and preserving the natural riparian corridor. Techniques for accomplishing these objectives include the following:

- Minimizing impervious surfaces
- Minimizing surface areas of permanent pools
- Preserving existing forested areas
- Bypassing existing baseflow and/or spring flow
- Providing shade-producing landscaping

The elevated temperatures are also caused by reduced shading in developed riparian areas. Pavement and other impervious surfaces tend to absorb substantial amounts of heat in summer due to their dark coloring and typically a lack of shade. This heat is transferred to runoff passing over the surface, resulting in runoff that is dramatically warmer than natural groundwater inflow would have been under a natural hydrologic cycle. Some BMPs, such as swales, shallow ponds and large impoundments can also increase the temperature of runoff, as it is quickly warmed on hot summer days before being discharged. Traditional peak reduction outlet structures and simple spillway outlets do nothing to cool the water before discharge. Thus, their use in proximity to cold water streams should be limited. Alternative BMPs, such as buffers, infiltration or under-drained filters can be used, or, if ponds are required, under-drained outlet structures can provide effective cooling. Equally important to maintaining cool stream temperature is preservation and/or restoration of riparian trees and shrubs to provide shade, particularly for headwater streams that are the root of the local ecosystem and the base of its food chain.

Temperature changes can be stressful and even lethal to many coldwater organisms. A rise in water temperature of just a few degrees Celsius over ambient conditions can reduce or eliminate sensitive stream insects and fish species such as stoneflies, mayflies and trout (Schueler, 1987). Of note, the WQS state that temperature for Class V streams should be 21^{o}C and Class VI streams should be 20^{o}C. Furthermore the temperature may not be raised by a discharge event in excess of 2^{o}C for Class V streams or 0.5^{o}C for Class VI streams.

6.9.6. Waters Where TMDLs Have Been Established

The federal Clean Water Act and 4 VAC 50-60-10 of the Virginia Stormwater Management Regulations define *Total maximum daily load* or *TMDL* as "the sum of the individual wasteload allocations for point sources or load allocations (LAs) for nonpoint sources, natural background loading and a margin of safety. TMDLs can be expressed in terms of either mass per time, toxicity, or other appropriate measure. The TMDL process provides for point versus nonpoint source trade-offs."

Under the Clean Water Act, water quality standards, which consist of both narrative and numeric criteria, are established to protect the physical, chemical, and biological integrity of surface waters and maintain designated uses. Under the authority of section 303(d) of the Clean Water Act, water bodies that do not meet water quality standards are considered “impaired,” and a “Total Maximum Daily Load” (TMDL) study must be conducted. This study computes the maximum pollutant load the water body can receive and still meet water quality standards, and it allocates this load to various point and nonpoint pollution sources, depending on what is causing the water quality impairment. Authorized states and tribes administer the TMDL program. In Virginia, the Department of Environmental Quality (DEQ) administers the TMDL program, as delegated from the EPA. The DEQ assists with developing TMDL implementation plans for waters with impairments due to nonpoint sources.

Currently, thousands of impaired waters are listed on state 303(d) lists. The Virginia 303(d) list of impaired waters can be found on the DEQ website at the following link:

http://www.deq.virginia.gov/wqa/ir2010.html

The most common sources of impairment associated with stormwater include sediment, pathogens (bacteria), nutrients, and metals (USEPA, 2007). However, stormwater and urban and suburban runoff are also significant contributors to impairments. For this reason, EPA and relevant state agencies are increasingly motivated to create a stronger link between TMDLs and stormwater permits, such as MS4, construction site, and industrial permits (USEPA, 2007; USEPA Region 5, 2007d, 2007e). With successive rounds of MS4 permits, permitted agencies will very likely need to apply more stringent stormwater criteria in impaired watersheds and/or provide a better match between particular pollutants of concern and selected BMPs.

Reflecting this point, section 4 VAC 50-60-54 E of the Virginia Stormwater Management Regulations, with the heading *Stormwater pollution prevention plan requirements*, states the following: “In addition to the above requirements, if a specific WLA for a pollutant has been established in a TMDL and is assigned to stormwater discharges from a construction activity, additional control measures must be identified and implemented by the operator so that discharges are consistent with the assumptions and requirements of the WLA in a State Water Control Board approved TMDL.”

For the local stormwater manager, this will require an effort to tailor certain stormwater criteria, watershed plans and BMPs to help meet TMDL pollutant reduction benchmarks. However, it is important to understand that efforts to (1) conserve and protect open space and sensitive resources, (2) buffer stream systems, (3) reduce runoff volume and infiltrate it or hold it for use on-site, and (4) provide treatment of runoff through other kinds of stormwater management practices, can provide significant results in addressing various kinds of urban and suburban water quality impairments.

6.9.6.1. Strategies for Local Stormwater Managers to Address TMDLs Through Special Stormwater Criteria

Depending on the nature of the TMDL and the implementation plan, local stormwater criteria can help address TMDL requirements. The following three general approaches are discussed in order of decreasing sophistication. There are other approaches that can applied, and a local program may find that a hybrid of several approaches is most applicable:

- Site-Based Load Limits
- Surrogate Measures for Sources of Impairment
- Presumptive BMP Performance Standards

A. Site-Based Load Limits

Some pollutants that are the basis for TMDLs are understood well enough that site-based load calculations can be done for each development and redevelopment site. These pollutants generally include sediment, phosphorus, and nitrogen. In some areas, other pollutants, such as ammonia, fecal coliform bacteria, and other pollutants can be added to the list if adequate local or regional studies have been conducted (MPCA, 2006). If site-based load limits are to be used, the TMDL and local stormwater program should have the following characteristics:

- The TMDL allocates a load reduction target to urban/developed land (preferably separating out existing developed land from estimates of future developed land).
- The local program uses (or plans to use) a method, such as the Simple Method (CWP and MDE, 2000), that allows for the calculation of pollutant loads for a particular site development project.
- The local, regional, or state manual (or policy document) contains a method to assign pollutant removal performance values to various structural and nonstructural BMPs. Low-Impact Development (LID) credits are another positive factor so that LID practices can be incorporated.

The general process for calculating site-based load limits is as follows:

Step 1: Based on the wasteload allocation (WLA) and load allocation (LA) in the TMDL, develop a site-based load limit for the pollutant of concern. The local program must allocate the total load reduction goal for urban/developed land to existing and future urban/developed land within the impaired watershed. The program should consider having a more flexible standard for redevelopment projects because the standard will usually be more difficult to meet for these projects.

> *Example: Site-based load limit = 0.28 pounds/acre/year for total phosphorus* (*Hirschman et al. 2008*) *That is, if each newly developed site meets the standard of 0.28 pound/acre/year, the load reduction goal for new urban/developed land can be met. In this context, other measures—such as stormwater retrofits and restoration projects—might have to be applied for existing urban/developed land (see Step 5 below and Schueler et al. 2007*).

Step 2: For each development site, the applicant should calculate the post-development load for the pollutant of concern using a recognized model or method. Most use impervious cover as the main basis for calculating loads, although other land covers (e.g., managed turf) are also important contributing sources.

Example: Post-development total phosphorus load = 0.55 pound/acre/year

Step 3: Next, the required load reduction is computed by comparing the post-development load to the site-based load limit, and an appropriate BMP is selected.

Example: Load reduction = post-development load – site-based load limit 0.55 – 0.28 = 0.27 pound/acre/year (load that must be removed to meet the load limit standard) Selected BMPs should be capable of removing the target load reduction. One way to determine this is to calculate the load leaving the BMP based on the expected effluent concentration and the effluent volume for the design storm (or on an annual basis).

Step 4: Select a combination of structural and nonstructural BMPs that can be documented to meet the required load reduction. If the local program and/or TMDL implementation plan encourages LID, then these practices should be assigned load reduction credits.

If the entire load reduction cannot be achieved (or is impractical) on the particular site, the applicant might be eligible to implement equivalent off-site BMPs within the impaired watershed. These off-site BMP may be implemented by the applicant on developed land that is currently not served by stormwater BMPs. As and alternative, the applicant can pay an appropriate fee (fee in lieu) to the local program to implement stormwater retrofits within the impaired watershed. In either case, full on-site compliance is being “traded” to implement other BMPs that can help achieve TMDL goals.

The local program would have to apply this technique to a variety of local plans to gauge achievability and feasibility across a range of development scenarios. A good real-world example of this approach (although not specific to impaired watersheds) is Maine’s *Phosphorus Control in Lake Watersheds: A Guide to Evaluating New Development*, which can be found at:

http://www.maine.gov/dep/blwq/docstand/stormwater/stormwaterbmps

B. Surrogate Measures for Sources of Impairment

If site-based load limits cannot be used because of the type of impairment (e.g., aquatic life) or limited data, surrogates that have a strong link to the cause of impairment can be used. For instance, various TMDLs have used impervious cover and stormwater flow as surrogates for stormwater impacts on aquatic life, stream channel stability, and habitat (USEPA, 2007). In these cases, the surrogates are relatively easy to measure and track through time. The TMDL might have a goal to reduce impervious cover and/or to apply BMP treatment to a certain percentage of impervious cover within the impaired watershed.

A local stormwater program could apply the surrogate approach through a tiered implementation strategy for new development and redevelopment:

- FIRST, minimize the creation of new impervious cover at the site through site design techniques. Preserve sensitive site features, such as riparian areas, wetlands, and important forest stands.
- SECOND, disconnect impervious cover by using LID and nonstructural BMPs.
- THIRD, install structural BMPs to reduce the impact of impervious cover on receiving waters.

C. Presumptive BMP Performance Standards

Perhaps the most widespread and simplest method to link TMDL goals with stormwater criteria is to presume that implementation of a certain suite of BMPs will lead to load reductions, and that monitoring and adaptive management can help adjust the appropriate template of BMPs over time (USEPA, 2007; USEPA Region 5, 2007d). This strategy acknowledges that data are often too limited to draw a conclusive link between particular pollutant sources and in-stream impairments. However, as more data becomes available and TMDL implementation strategies are refined, a more quantitative method, such as the two noted above, should be pursued.

There are a wide variety of "presumptive" BMPs that can be included in local stormwater criteria for an impaired watershed, and these should be adapted based on the pollutant(s) of concern:

- Stream/wetland/lake setbacks and buffers
- Site reforestation
- Soil enhancements
- Incentives for redevelopment

Requirements for runoff reduction:

- Implementation of LID
- Requirements for BMPs with filter media and/or vegetative cover
- Enhanced sizing and/or pre-treatment requirements
- Required BMPs at stormwater hotspots or particular land use categories (e.g., marinas, industrial operations)
- Contribution to stormwater retrofit projects within the watershed

The "providing channel protection" criterion is highly recommended for receiving waters that are impaired by sediment or sediment-related pollutants. Given the importance of channel erosion in the sediment budget of urban streams, it is critical to control erosive flows from development projects.

For more information on linking TMDLs to stormwater permits, see the following:

Total Maximum Daily Loads with Stormwater Sources: A Summary of 17 TMDLs, EPA 841-R-07-002, at:

http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/17_TMDLs_Stormwater_Sources.pdf

Total Maximum Daily Loads and National Pollutant Discharge Elimination System Stormwater Permits for Impaired Waterbodies: A Summary of State Practices, USEPA, at:

http://www.epa.gov/r5water/wshednps/pdf/state_practices_report_final_09_07.pdf

Incorporating Green Infrastructure Concepts into Total Maximum Daily Loads (TMDLs), USEPA at:

http://water.epa.gov/aboutow/owow/upload/tmdl_lid_final.pdf

For a comprehensive primer on stormwater retrofitting in existing urban/developed land, see: ***Urban Stormwater Retrofit Practices, Manual 3***, 2008, *Urban Subwatershed Restoration Manual Series*, Center for Watershed Protection, at:

http://www.cwp.org/documents/cat_view/68-urban-subwatershed-restoration-manual-series/89-manual-3-urban-stormwater-retrofit-practices-manual.html

To obtain even more information on creating a stronger link between stormwater criteria and TMDLs, refer to Chapter 4 of the Center for Watershed Protection's ***Post-Construction SWMP Program Guidance Manual,* at:**

http://www.cwp.org/documents/doc_details/200-managing-stormwater-in-your-community-a-guide-for-building-an-effective-post-construction-program.html?tmpl=component

6.9.7. Ultra Urban Settings

Accomplishing Environmental Site Design at ultra-urban development and redevelopment sites is challenging, since population is dense and space is extremely limited, land is expensive, soils are disturbed, and runoff volumes and pollutant loadings are great, and there is a wide range of potential pollutants. These sites do, however, present a great opportunity for making progress in stormwater management where it has not previously existed. Much of the opportunity is focused on BMP selection and design, as well as cohesive integration of the BMP treatment train into the development scheme. BMP selection for ultra-urban sites is addressed in **Section 8.6.1 and Table 8.3 of Chapter 8** of this Handbook. BMP designs aimed specifically at ultra-urban settings can be found in Attachment D of the *Baltimore City Stormwater Management Manual.* Such designs may be considered for approval by local plan review authorities as innovative/alternative designs, provided sufficient design/routing information is included.

6.10. REFERENCES

ADA Hotline. 1997. Personal Communication. Americans with Disabilities Act Hotline. Washington, DC.

American Association of State Highway and Transportation Officials (AASHTO). 1994. *A Policy on the Geometric Design of Highways and Streets.* No. 33. Washington, DC.

American Forests. 2001. "Regional Ecosystem Analysis for the Willamette/Lower Columbia Region of Northwestern Oregon and Southwestern Washington State." *American Forests (October 2001).* "Urban Ecosystem Analysis: Atlanta Metro Area: Calculating the Value of Nature." *American Forests (August 2001).*

American Society of Landscape Architects (ASLA), the Lady Bird Johnson Wildflower Center at the University of Texas at Austin, and the United States Botanic Garden. 2009. *The Sustainable Sites Initiative™: The Case for Sustainable Landscapes.* Available online at: http://www.sustainablesites.org/ (accessed January 14, 2010)

American Society of Landscape Architects (ASLA), the Lady Bird Johnson Wildflower Center at the University of Texas at Austin, and the United States Botanic Garden. 2009. *The Sustainable Sites Initiative™: Guidelines and Performance Benchmarks 2009.* Available online: http://www.sustainablesites.org/ (accessed January 14, 2010)

Andreasen, Alan and C. Tyson. 2993. *Improving Tree Management Practices of Home Builders: A Social Marketing Approach.* Forest Policy Center. American Forests. Washington, DC.

Arendt, R. 1994. *Rural By Design*. American Planning Association. Planners Press. Washington, D.C.

Arendt, R. 1997. *Designing Open Space Subdivisions*. Natural Lands Trust. Media, PA

Atlanta Regional Commission (ARC). 2001. *Georgia Stormwater Management Manual*. Prepared by AMEC, the Center for Watershed Protection, Debo and Associates, Jordan Jones and Goulding, and the Atlanta Regional Commission. Atlanta, Georgia.

Azous, A. L. and R. R. Horner, Editors. 1997. *Wetlands and Urbanization: Implications for the Future*. (Final report of the Puget Sound Wetlands and Stormwater Management Research Program). Washington State Department of Ecology. Olympia, WA. University of Washington. Seattle, WA.

Bannerman, R. et al. 1993. "Sources of Pollutants in Wisconsin Stormwater." *Water Science Technology, 28(3-5): 241-259.*

Braden, J. B., and D. M. Johnston. 2004. "Downstream Economic Benefits from Stormwater Management." *Journal of Water Resources Planning and Management 130.* pp. 498-505.

Buchman, S. L., and G. P. Nabhan. 1996. *The Forgotten Pollinators*. p. 312. Island Press. Washington, DC.

Burchell, Robert W. and David Listokin. 1995. *Land, Infrastructure, Housing Costs and Fiscal Impacts Associated with Growth:* The *Literature on the Impacts of Sprawl v. Managed Growth.* Lincoln Institute of Land Policy. Cambridge, MA.

Burchell, Robert W., N. Shad D. Listokin, and H. Phillips. 1998. *The Costs of Sprawl – Revisited.* Transportation Research Board TCRP Report 39, National Research Council, Washington, DC.

Cappiella, K. 2005a. *Urban Watershed Forestry Manual Part 1: Conserving Trees at the Watershed Scale*. Prepared for: USDA Forest Service. Center for Watershed Protection. Ellicott City, MD.

Cappiella, K., T. Schueler, and T. Wright. 2005b. *Urban Watershed Forestry Manual Part 2: Conserving and Planting Trees at Development Sites*. Prepared for the USDA Forest Service. Center for Watershed Protection. Ellicott City, MD.

D. Caraco and R. Claytor. December, 1997. *Stormwater BMP Design Supplement for Cold Climates.* Center for Watershed Protection. Ellicott City, MD. Available online at:
http://www.cwp.org/Resource_Library/Center_Docs/special/ELC_coldclimates.pdf

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared for the US EPA Office of Wetlands, Oceans and Watersheds and US EPA Region 5. CWP. Ellicott City, Maryland.

Center for Watershed Protection (CWP). 1998a. *Better Site Design: A Handbook for Changing Development Rules in Your Community*. Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection (CWP). 1998b. *Nutrient Loading From Conventional and Innovative Site Development*. Prepared for the Chesapeake Research Consortium. Center for Watershed Protection. Ellicott City, MD.

Center for Waterhsed Protectino (CWP) and Maryland Department of the Environment (MDE). 2000a. *2000 Maryland Stormwater Design Manual, Volumes I and II.* Maryland Department of the Environment. Baltimore, MD.

Center for Watershed Protection (CWP). 2000b. *Better Site Design: An Assessment of the Better Site Design Principles for Communities Implementing Virginia's Chesapeake Bay Preservation Act.* available at:

http://www.dcr.virginia.gov/chesapeake_bay_local_assistance/documents/bsd_brochure.pdf.

Center for Watershed Protection (CWP). 2003. *The Economic Benefits of Better Site Design in Virginia*. Ellicott City, MD.

Center for Watershed Protection (CWP). 2008. Urban Subwatershed Restoration Manual 3, *Urban Stormwater Retrofit Practices*. Ellicott City, MD. Available online at: http://www.cwp.org/documents/cat_view/68-urban-subwatershed-restoration-manual-series/89-manual-3-urban-stormwater-retrofit-practices-manual.html

Center for Watershed Protection (CWP). June, 2008a. Urban Subwatershed Restoration Manual 9, "Chapter 4: Hotspot Facility Management". Ellicott City, MD. Available online at: http://www.cwp.org/Resource_Library/Center_Docs/municipal/USRM9.pdf

Center for Watershed Protection (CWP). July, 2008b. *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program*. Ellicott City, MD. Available online at: http://www.cwp.org/documents/doc_details/200-managing-stormwater-in-your-community-a-guide-for-building-an-effective-post-construction-program.html?tmpl=component

Chesapeake Bay Foundation (CBF). 1996. *A Dollars and Sense Partnership: Economic Development and Environmental Protection.* Annapolis, MD. 21 pp.

Coder, Dr. Kim D. 1996. *Identified Benefits of Community Trees and Forests.* University of Georgia Cooperative Extension Service. Forest Resources Unit. Publication FOR96-39.

Commonwealth of the Northern Marianna Islands and the Territory of Guam. 2006. *CNMI and Guam Stormwater Management Manual* (Draft). Prepared by the Horsely Witten Group, Inc.

Cooper, K. June 8, 2008. "Water Is the New Oil." *(London) Times Online.* Available online at: http://www.timesonline.co.uk/tol/money/article4086457.ece (accessed September 26, 2009)

Correll, Mark R., Jane H. Lillydahl and Larry D. Singell. 1978. "The Effects of Greenbelts on Residential Property Values: Some Findings on the Political Economy of Open Space." *Land Economics 54(2).*

Costanza, R., R. d'Arge, R. deGroot, et al. 1997. "The Value of the World's Ecosystem Services and Natural Capital." *Nature 387, no 6630.* pp. 253-260.

Dahl, T, 2006. *Status and Trends of Wetlands in the Coterminous United States: 1998-2004*. U.S. Department of Interior. Fish and Wildlife Service. Washington, DC.

Daniels, Stevie. 1995. *The Wild Lawn Handbook: Alternatives to the Traditional Front Lawn.* Macmillan Press. New York, NY. 223 pages.

Day, Gary E. and C. Scott Crafton. 1978. *Site and Community Design Guidelines for Stormwater Management.* College of Architecture and Urban Studies. Virginia Polytechnic Institute and State University. Blacksburg, VA.

DeGroot, R. S., M. A. Willson, and R. M. J. Boumans. 2002. "A Typology for the Classification, Description and Valuation of Ecosystem Functions, Goods and Services." *Ecological Economics 41, no. 3.* pp. 393-408.+

Delaware Department of Natural Resources and Environmental Conservation (DE DNREC). 1997. *Conservation Design for Stormwater Management*. Dover, DE.

Dey, T. 1997. *The Real Influence of the Americans with Disabilities Act (ADA) on Local Design Standards.* Widener University Environmental Law Clinic. Philadelphia, PA.

Dreher, D, and T. Price. 1994. *Reducing the Impact of Urban Runoff: The Advantages of Alternative Site Design Approaches*. Northeastern Illinois Planning Commission. Chicago, IL.

Erlich, P. 1985. "The Concept of Human Ecology: A Personal View." *IUCN Bulletin 16 (no. 4-6).* pp. 60-61.

Ewing, R. 1996. *Development Practices: Doing the Right Thing and Making Money at the Same Time.* American Planning Association. Chicago, IL.

Fausold, C. and R. Lilieholm. 1996. *The Economic Value of Open Space: A Review and Synthesis.* Lincoln Institute of Land Policy. Cambridge, MA.

Firewise Communities. *Firewise Communities: A Model of Local Initiative and Cooperation.* At: http://www,firewise.org/newsroom/files/firewise_communities_fact_sheet_040307.pdf (accessed on August 20, 2008)

Flannery, T. 2005. *The Weather Makers.* Grove Press. New York, NY. p. 357.

Georgia Department of Natural Resources. April 2009. *Coastal Stormwater Supplement to the Georgia Stormwater Management Manual.* Prepared by the Center for Watershed Management. Ellicott City, MD. At: http://www.cwp.org/Resource_Library/Center_Docs/SW/georgia_css.pdf

Heraty, M. 1992. *An Assessment of the Applicability of Cluster Development Regulations as a Nonpoint Source Pollution Best Management Practice.* Metropolitan Washington Council of Governments. Produced for the USEPA Office of Wetlands, Oceans and Watersheds. Washington, DC.

Hirschman, D., Collins, K., and T. Schueler. 2008. *Technical Memorandum: The Runoff Reduction Method.* Prepared for: "Extreme BMP Makeover – Enhancing Nutrient Removal Performance for the Next Generation of Urban Stormwater BMPs in the James River Basin" and to provide technical assistance in revision of the Virginia Stormwater Management Regulations and Handbook. Center for Watershed Protection. Ellicott City, MD.

Illinois Conservation Foundation and Chicago Wilderness. 2005. *Changing Cost Perceptions: An Analysis of Conservation Development*. Prepared by the Conservation Research Institute. www.nipc.org/environment/sustainable/conservationdesign/cost_analysis

Institute of Transportation Engineers Transportation Planning Council Committee 5P-8 (ITE). 1997. *Traditional Neighborhood Development Street Design Guidelines*. Institute of Transportation Engineers. Washington, DC.

Liptan, T. and C. Brown. 1996. *A Cost Comparison of Conventional and Water Quality-based Stormwater Designs*. City of Portland, OR.

Loizeaux-Bennet, S. 1999. “Stormwater and Nonpoint Source Runoff: A Primer on Stormwater Management.” *Erosion Control 6, No. 7*. pp. 56-59. Forester Media, Inc. Santa Barbara, CA.

Los Angeles County (California) Department of Public Works. September, 2002. *Development Planning for Storm Water Management: A Manual for the Standard Urban Storm Water Mitigation Plan (SUSMP)*. Available at: http://ladpw.org/wmd/npdes/SUSMP_MANUAL.pdf

MacDonald, L. 1996. “Forests and the Quality of the Urban Environment.” *American Forests*. Autumn, 1996.

Maine Department of Environmental Protection. 2008. *Stormwater Management for Maine – Volume II: Phosphorus Control in Lake Watersheds – A Technical Guide to Evaluating New Development*. No. DEPLW0738. Augusta, ME. Available online at: http://www.maine.gov/dep/blwq/docstand/stormwater/stormwaterbmps

Markowitz, F. August 1995. *Shared Parking Planning Guidelines*. Institute of Transportation Engineers, Washington, DC.

Marsh, W. 1983. *Landscape Planning: Environmental Applications*. John Wiley & Sons. New York, NY.

Maurer, G. 1996. *A Better Way to Grow: For More Livable Communities and a Healthier Chesapeake Bay*. Chesapeake Bay Foundation. Annapolis, MD.

McDonald, F. 1999. *Ecologically Sound Lawn Care for the Pacific Northwest: Findings from the Scientific Literature and Recommendations from Turf Professionals*. City of Seattle Public Works. Seattle, WA.

McHarg, Ian. 1969. *Design With Nature*. Natural History Press/Falcon Press. Philadelphia, PA

McPherson, G., D. J. Nowak, and R. A. Rowntree. 1994. *Chicago’s Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project.* USDA Forest Service and Northeastern Forest Experiment Station. General Technical Report NE-186, Available online at: http://www.treesearch.fs.fed.us/pubs/4285 (accessed on October 10, 2009)

Mehta, P. K. 2001. “Reducing the Environmental Impact of Concrete.” *Concrete International (October 2001).* pp. 61-66.

Michael, H. J., K. J. Boyle and R. Rouchard. 1996. *Water Quality Affects Property Prices: A Case Study of Selected Maine Lakes.* University of Maine Agricultural and forest Experimentation Station. Miscellaneous Report 398. 15 pp.

Millenium Ecosystem Assessment (MEA). 2003. *Ecosystems and Human Well-Being: Message from the Board*. Island Press. Washington, DC.

Minnesota Pollution Control Agency (MPCA). 1989. *Protecting Water Quality in Urban Areas*. St. Paul, MN.

Minnesota Pollution Control Agency (MPCA). January, 2005. *Issue Paper G:. Cold Climate Considerations for Surface Water Management*. Prepared by Emons & Oliver Resources and the Center for Watershed Protection. St. Paul, MN. http://www.pca.state.mn.us/publications/wq-strm8-14be.pdf

Minnesota Pollution Control Agency (MPCA). June, 2005. *Issue Paper H: Potential Stormwater Hotspots, Pollution Prevention, Groundwater Concerns and Related Issues, version 3 (final)*. Prepared by Emons & Oliver Resources and the Center for Watershed Protection. St. Paul, MN. Available online at: http://www.pca.state.mn.us/publications/wq-strm8-14bf.pdf

Minnesota Pollution Control Agency (MPCA). 2006. *Minnesota Stormwater Manual*. St. Paul, MN.

Morales, D. J. 1980. "The Contribution of Trees to residential Property Values." *Journal of Arboriculture 6(11): 301-302*.

National Arbor Day Foundation. 1996. "Placing a Value on Trees." *Tree City USA Bulleting No. 28*. Dr. James R. Fazio, Editor. Nebraska City, NE.

National Association of Home Builders (NAHB). 1986. *Cost Effective Site Planning*. Washington, DC.

National Association of Home Builders (NAHB). 1997. *Housing Facts and Figures*. Washington, DC.

National Highway Institute (NHI). 1996. *Pedestrian and Bicyclist Safety and Accommodations*. U.S. Department of Transportation, Federal Highway Administration. National Highway Traffic Safety Administration. Maclean, VA. Publication # FHWA-HI96-029. NHI Course No. 38061.

National Wildland/Urban Interface Fire Protection Program. *Fire Protection in the Wildland/Urban Interface: Everyone's Responsibility*. National Interagency Fire Center. Boise, ID.

National Research Council (NRC) of the National Academies of Science. 2004. *Valuing Ecosystem Services: Toward Better Environmental Decision-Making*. National Academies Press. Washington, DC.

New York State Department of Environmental Conservation. April 2008. *New York State Stormwater Management Design Manual*. Albany, NY. Available online at: http://www.dec.ny.gov/docs/water_pdf/swdmappendixi.pdf

North Carolina Department of Environment and Natural Resources (NCDENR). 1998. *Stormwater Management Site Planning*.

Northern Shenandoah Valley Regional Commission. 2005. *Northern Shenandoah Valley Regional LID Manual.* Prepared by Engineering Concepts, Inc.

Peper, P. J., E. G. McPherson, J. R. Simpson, et al. 2007. *New York City, New York: Municipal Forest Resource Analysis.* Center for Urban Forest Research, USDA Forest Service, and the Pacific Southwest Research Station. Available online at: http://www.urbanforestrysouth.org/resources/library/new-york-city-new-york-municipal-forest-resource-analysis (accessed on October 10, 2009)

Pimentel, D., R. Zuniga, and D. Morrison. 2000. "Environmental and Economic Costs of Non-indigenous Species in the United States." *BioScience 50, No. 1.* pp. 53-65. Available at: http://www.bioone.org/doi/abs/10.1641/0006-3568(2000)050%5B0053%3AEAECON%5D2.3.CO%3B2?journal Code=bsi

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2005. "Environmental and Economic Costs Associated with Alien-Invasive Species in the United States." *Ecological Economics 52*. pp. 273-288.

Pitt, R. E. 1987. *Small Storm Urban Flow and Particulate Washoff Contributions to Outfall Discharges.* Doctoral Thesis. University of Wisconsin. Madison, WI.

Prince George's County, MD. 1999. *Low-Impact Development Design Strategies: An Integrated Design Approach*.

Puget Sound Action Team. May 2005. *Low Impact Development Technical Guidance Manual for Puget Sound.* Office of the Governor. Olympia, WA.

Sacramento County and the City of Roseville, California. 2007. *Stormwater Quality Design Manual for the Sacramento and South Placer Regions*.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Metropolitan Washington Council of Governments, Washington, D.C.

Schueler, T. 1995. *Site Planning for Urban Stream Protection*. Prepared by Center for Watershed Protection (CWP) for the Metropolitan Washington Council of Governments. Washington, DC.

Schueler, T. *Snow, Road Salt and the Chesapeake Bay.* Center for Watershed Protection. Ellicott City, MD. Available online at: http://www.cwp.org/Resource_Library/Special_Resource_Management/ColdClimate/snow_road salt_chesbay.pdf

Schueler, Hirschman, D., Novotney, M., and J. Zielinski. 2007. Draft Urban Subwatershed Restoration Manual 3, *Urban Stormwater Retrofit Practices*. Center for Watershed Protection. Ellicott City, MD. Available online at: http://www.cwp.org/documents/cat_view/68-urban-subwatershed-restoration-manual-series/89-manual-3-urban-stormwater-retrofit-practices-manual.html

Schueler, T. 2009. *CSN Technical Bulletin No. 1: Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed*. Chesapeake Stormwater Network. Baltimore, MD. http://www.chesapeakestormwater.net/welcome/ .

Schueler, T. 2009. *CSN Technical Bulletin No. 2: Stormwater Design in the Coastal Plain of the Chesapeake Bay Watershed*. Chesapeake Stormwater Network. Baltimore, MD. http://www.chesapeakestormwater.net/welcome/ .

Shaw, D. and R. Schmidt. 2003. *Plants for Stormwater Design: Species Selection for the Upper Midwest*. Edited by S. Brungardt, Designed by R. Harrison. Minnesota Pollution Control Agency. St. Paul, MN.

Siemon, Larsen & Purdy: Rogers, Golden & Halpern, Inc.; and Hammer, Siler, George Associates. 1990. *Crossroads: Two Growth Alternatives for Virginia Beach.* Office of Planning. City of Virginia Beach, VA.

Smith, K. A., T. Ball, F. Conen et al. 2003. "Exchange of Greenhouse Gases Between Soil and Atmosphere: Interactions of Sil Physical Factors and Biological Processes." *European Journal of Soil Science 54.* pp. 779-791.

Smith, Thomas. 1984. *Flexible Parking Requirements.* Planning Advisory Service Report No. 377. American Planning Association. Chicago, IL. 40 pp.

Society of American Foresters Council (SAFC). *Wildfire Management: A Position of the Society of American Foresters.* Society of American Foresters. Available online at: http://www.safnet.org/fp/documents/wildland_fire.pdf (accessed on July 16, 2009)

South Carolina Coastal Conservation League (SCCCL). 1995. "Getting a Rein on Runoff: How Sprawl and Traditional Town Compare." *SCCCL Land Development Bulleting (Number 7, Fall 1995)*. Charleston, SC.

Steiner, C. and J. Loomis. 1996. *Estimating the Benefits of Urban Stream Restoration Using the Hedonic Price Method.* Dept. of Agriculture and Resource Economics. Colorado State University. Fort Collins, CO. 18 pp.

Steuer, et al. 1997. *Sources of Contamination in an Urban Basin in Marquette, Michigan and an Analysis of Concentrations, Loads, and Data Quality.* U.S. Geological Survey Water Resources Investigation Report No. 97-4242.

Sykes, R.D. 1989. Chapter 31 – Site Planning. University of Minnesota.

United Nations General Assembly. 1987. *Our Common Future: Report of the World Commission on Environment and Development.* New York, NY. Available online at: http://www.worldinbalance.net/agreements/1987-brundtland.html (accessed October 11, 2009)

U.S. Environmental Protection Agency (EPA). 2003. *Estimating 2003 Building-Related Construction and Demolition Materials Amounts.* Available online at: http://www.epa.gov/epawaste/conserve/rrr/imr/cdm/pubs/cd-meas.pdf (accessed on October 22, 2009)

U.S. Environmental Protection Agency (EPA). 2005. *Stormwater Phase II Final Rule: Construction Site Runoff Control Minimum Control Measures.* EPA 833-F-00-008 (2005). At: http://www.epa.gov/npdes/docs.cfm?document_type_id=3&view=3&program_id=6&sort=date_published (accessed October 10, 2009)

U.S. Environmental Protection Agency (EPA). 2007. *Total Maximum Daily Loads with Stormwater Sources: A Summary of 17 TMDLs.* EPA 841-R-07-002. Washington, DC. Available online at: http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/17_TMDLs_Stormwater_Sources.pdf

U.S. Environmental Protection Agency (EPA). 2007a. *Reducing Stormwater Costs Through Low Impact Development (LID) Strategies and Practices*. Washington, DC. Available online at: http://www.epa.gove/WaterSense/docs/ws_outdoor508.pdf (accessed July 14, 2009)

U.S. Environmental Protection Agency (EPA). 2007b. *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2007.* Available online at: http://www.epa.gov/waste/honhaz/municipal/msw99.htm (accessed on October 10, 2009).

U.S. Environmental Protection Agency (EPA). 2007c. *Wetlands Functions and Values.* At: http://www.epa.gov/watertrain/wetlands/module05.htm (accessed on October 10, 2009)

U.S. Environmental Protection Agency (EPA). 2007d. *Total Maximum Daily Loads and National Pollutant Discharge Elimination System Stormwater Permits for Impaired Water Bodies: A Summary of State Practices*, USEPA Region 5. Chicago, IL. Available online at: http://www.epa.gov/r5water/wshednps/pdf/state_practices_report_final_09_07.pdf

U.S. Environmental Protection Agency (EPA). 2007e. *Incorporating Green Infrastructure Concepts into Total Maximum Daily Loads (TMDLs)*, USEPA Region 5. Chicago, IL. Available online at: http://water.epa.gov/aboutow/owow/upload/tmdl_lid_final.pdf

U.S. Environmental Protection Agency (EPA). August, 2008. "Outdoor Water Use in the United States." *EPA WaterSense*. DPA 832-F-06-005. Available online at: http://www.epa.gov/WaterSense/docs/ws_outdoor508.pdf (accessed July 14, 2009)

United States Geological Survey. 2006. *Sustainability of Ground-water Resources in the Atlantic Coastal Plain of Maryland*. Maryland DNR and DOE. USGS Fact Sheet FS 2006-3009.

U.S. Water News. 1997. "Loss of Trees in Atlanta Area Produces Increased Stormwater Costs." *U.S. Water News Online.* August, 1997.

Urban Land Institute (ULI). 1992. *Density by Design (DBD).* James W. Wetling and Lloyd W. Bookout, editors. Washington, DC.

Veni, George, DuChene, H., Crawford, N., Groves, C., Huppert, G., Kastning, E., Olson, R., and Wheeler, B., 2001, *Living with Karst: A Fragile Foundation.* American Geological Institute, Alexandria, VA, 65 pages.

Virginia Department of Conservation and Recreation (DCR). 2003. *Riparian Buffers Modification & Mitigation Guidance Manual.* Richmond, VA. Available online at: http://www.dcr.virginia.gov/chesapeake_bay_local_assistance/ripbuffmanual.shtml

Virginia LID Work Group (LIDWG). 2005. *Draft Technical Bulletin*.

Virginia Polytechnic Institute and State University (VPI&SU). 2000. *Water Sensitive Site Planning*. College of Architecture and Urban Studies.

Washington State Department of Ecology. September 2004. *Stormwater Management Manual for Eastern Washington.* Publication No. 04-10-076. http://www.ecy.wa.gov/pubs/0410076.pdf .

Washington State Department of Ecology. February 2005. *Stormwater Management Manual for Western Washington, Volume IV: Source Control BMPs.* Publication No. 05-10-32, which is a revised portion of Publication No. 91-75. Water Quality Program. Available online at: http://www.ecy.wa.gov/pubs/0510032.pdf

Wells, C. 1994. *Impervious Surface Reduction Technical Study*. Draft Report. City of Olympia Public Works. Water Resources Program. Olympia, WA. 182 pp.

Weyerhauser Company. 1989. *The Value of Landscaping.* Weyerhauser Nursery Products Division. Tacoma, WA.

White, W.B., D.C. Culver, J.S. Herman, T.C. Kane, and J.E. Mylroie. 1995. "Karst Lands." *American Scientist*. 83:450-459.

Witten, Jon and Scott Horsley. 1995. *A Guide to Wellhead Protection.* American Planning Association. Chicago, IL.

Xiao, Q., E. G. McPherson, S. L. Ustin and M. E. Grismer. 2000a. "A New Approach to Modeling Tree Rainfall Interception." *Journal of Geophysical Research 105(D23): 29, 173-29, 188*.

Xiao, Q., E. G. McPherson, S. L. Ustin, M.E. Grismer, and J. R. Simpson. 2000b. "Winter Rainfall Interception by Two Mature Open Grown Trees in Davis, California." *Hydrological Processes. 14(4): 763-784*.

Zielinski, J. 2001. "The Benefits of Better Site Design in Residential Subdivisions." *Watershed Protection Techniques, 3(2):633-646*. Center for Watershed Protection. Ellicott City, MD.

Zokaites, Carol, editor, 1997, *Living on Karst*: A *Reference Guide for Landowners in Limestone Regions*: Cave Conservancy of the Virginias, Glen Allen, VA, 26 pages.